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An Analysis of the Water Situation in the United States: 1989 — 2040

A Technical Document Supporting the 1989 RPA Assessment

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A Technical Document Supporting the 1989 RPA Assessment

Richard W. Guldin

FOREWORD

Since the 1979 Assessment was prepared and last updated in 1984, we have made significant strides in our capabilities to assess current and projected future renewable resource situations. More and better data have become available. Our analytical techniques have improved, largely due to research advances. This draft report is the first place where all these improvements have been consolidated into a national analysis.

Our results show that the Nation's demands for outdoor recreation, wildlife and fish, timber, and water have grown rapidly since 1970. Demands for range forage and mineral products have also grown, but at a slower rate than in the past. Economic and demographic factors that are the principal determinants of demand, such as gross national product and population are also expected to continue increasing in the future. Thus, this report projects continued increases in demands for renewable resources over the next 50 years.

Although projected growth in demand differs for the various products, the increases are still greater than the levels that can be supplied with present resource management programs and existing physical facilities. Continuation of present resource management will lead to a future of intensified competition for the available supplies of renewable resource products, and resulting adverse impacts on the natural environment, the economy, and the general quality of life in America.

If we want to change this future, we need to take steps to increase the productivity of the Nation's forests, rangelands, and waters.

Many opportunities exist on the 1.7 billion acres of forest and rangeland and associated waters to increase and extend supplies of nearly all renewable resource products. The Nation's lands and waters have the physical capacity to supply sites for recreation well in excess of expected increases in demand and to support much larger numbers of most species of wildlife and fish. Under more intensive management, the forests can produce additional timber while still providing amenities. The quality of water emanating from forests and rangeland can be improved and damages from floods reduced. Reducing abusive land management practices can boost soil productivity.

Although many opportunities exist, obstacles in our current institutional structures at the federal, state, and local levels preclude realizing many of these opportunities with current management programs. Both private and public actions will be needed to capture the opportunities to increase the productivity of renewable resources and maintain environmental quality.

We have sent you this copy of the draft report for review. Please send us your comments on our analyses of the demand and supply situation and implications and our assessment of resource management opportunities and obstacles. Mail your comments by October 15, 1988 to:

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PREFACE

The Renewable Resources Planning Act of 1974 (RPA), Public Law 93-378 (88 Stat. 475, as amended), directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979, and each tenth year thereafter. The Assessment is to include "an analysis of the present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand, and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and future outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, water, timber and minerals. The complete analyses for each of these resources are contained in separate supporting technical documents. There are also technical documents presenting information on interactions among the various resources; the basic assumptions for the Assessment; an overview of the evolving use and management of forests, grasslands, croplands and related resources; and a description of Forest Service programs.

The 1989 RPA Assessment continues a resource analysis heritage that the Forest Service has been carrying out in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report upon forest conditions. Between 1880 and 1974, a number of assessments of the timber resource situation were prepared at irregular intervals. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber alone to all renewable resources from forests and rangelands.

ACKNOWLEDGEMENTS

A decade has passed since publication of The Nation's Water Resources: 1975-2000 by the Water Resources Council. The 1979 RPA Water Assessment and the 1984 Assessment Update drew heavily upon that report. But because the data for the former report are now 15 years old, new data and new projections were needed for this report. The literature on water resources has expanded tremendously in the past 15 years, due largely to the proliferation of research and reports in response to the Clean Water Act. Susan Johnson reviewed more than 1000 abstracts and screened hundreds of publications for this report. Without her help, this report could not have been written. Joan Miller deserves thanks for overseeing the publication process.

Wayne Solley, Geological Survey, provided data that was essential to making projections of water withdrawals and consumption.

Several people reviewed part or all of the manuscript. These include Peter Avers, Richard Cline, David Darr, Thomas Hamilton, Warren Harper, Fred Kaiser, Kermit Larson, Robert Moulton, John Nordin, Dean Rasmuson, Gray Reynolds, Larry Schmidt, Rhey Solomon, and Gordon Stuart. They helped prevent many errors of omission and commission.

In spite of all this assistance, perfection has not been attained. I alone am responsible for the errors that remain.

R.W.G.
Washington, DC
July 24, 1988

TABLE OF CONTENTS

CHAPTER 1 -- THE CURRENT RESOURCE SITUATION FOR WATER IN THE UNITED STATES

Introduction ....I- 1

Precipitation Patterns ....I- 2
Runoff-Precipitation Relationships ....I- 4
The Role of Climate ....I- 4
The Role of Topography ....I- 6
The Role of Geology ....I- 6
Seasonal Runoff and Streamflow Variations ....I- 7
Annual Flow Variations--Droughts and Floods ....I- 7
Droughts ....I- 8
Floods ....I- 8

Watershed Condition I-10
Class I: Regimen Attainment I-11
Class II: Special Emphasis I-11
Class III: Investment Emphasis I-12
Summary I-14

Quantity of Water Available for Use I-14
Instream versus Offstream Uses I-14
Groundwater Development I-15
Aquifer Declines I-16
The High Plains I-18
Central Valley California I-19
Southeastern and Atlantic Coastal Plain I-19
Arizona Lowlands I-20
Groundwater Summary I-20
Instream Use I-21
Types of Uses I-21
Generalized Water Budgets I-22
Surface Water Development I-22
Structural Surface Water Developments I-25
Controlling Losses and Low Priority Uses I-28
Increasing Precipitation I-29
Using Low Quality Water I-29

Quality of Water Available for Use I-30
Point-Source Pollution I-32
Biochemical Oxygen Demand I-33
Bacteria I-33
Mine Drainage I-33
Nonpoint-Source Pollution I-35
Suspended Sediment I-36

TABLE OF CONTENTS (Continued)

Total Phosphorus I-36
Total Nitrates I-38
Total Dissolved Solids (Salinity) I-39
Toxics I-40

Resource Management Externalities Affect Water Resources I-45
Acid Deposition I-46
Description and Sources I-46
Linkages to Other Air Quality Problems I-47
The Mandate to Study Acid Deposition I-47
Implications for Aquatic Ecosystems I-49
Implications for Forests I-50
Erosion I-52
Biological Impacts of Erosion I-52
Recreational Impacts of Erosion I-52
Erosion Damages to Water Storage I-53
Impacts of Erosion on Navigation I-53
Other Instream Impacts of Erosion I-53
Flood Damages of Erosion I-54
Water-Conveyance Impacts of Erosion I-54
Water-Treatment Impacts of Erosion I-54
Other Offstream Impacts of Erosion I-54
Summary I-54
Groundwater Contamination I-56
Source and Scope of Groundwater Contamination I-56
Underground Storage Tanks I-57
Septic Tanks I-57
Agricultural Activities I-57
Landfills I-58
Hazardous Wastes I-59
A Groundwater Protection Strategy I-59
Summary I-60

Condition and Distribution of the Nation's Wetlands I-61
Present Distribution of Wetlands by Size and Region I-61
Influence of Wetlands on Reducing Peak Flow Rates I-64
Influence of Wetlands on Maintaining Water Quality I-64
Regulations Influencing Wetlands Conversion I-66

Literature Cited I-67

References Cited--Unpublished I-71

Notes I-72

CHAPTER 2 -- THE DEMAND SITUATION FOR WATER

Historical Overview of the Demand for Water .....II- 1

TABLE OF CONTENTS (Continued)

Historical Data on Water Withdrawals and Consumption ....II- 2
National Trends in Withdrawals and Consumption ....II- 2
National Trends by Water Use ....II- 4
National Trends by Water Source ....II- 4
Regional Trends in Withdrawals and Consumption ....II- 4

Projected Demands for Water ....II- 9
Thermoelectric Steam Cooling II-10
Description of the Use II-10
Magnitude of Water Use and Trends II-15
Potential for Changes in the Projection II-15
Irrigation II-20
Description of the Use II-20
Magnitude of Water Use and Trends II-22
Potential for Changes in the Projection II-27
Municipal Central-Supplied Water Use II-28
Description of the Use II-28
Magnitude of Water Use and Trends II-28
Potential for Changes in the Projection II-30
Industrial Self-Supplied Water Use II-34
Description of the Use II-34
Magnitude of Water Use and Trends II-34
Potential for Changes in the Projection II-39
Domestic Self-Supplied Water Use II-40
Description of the Use II-40
Magnitude of Water Use and Trends II-41
Potential for Changes in the Projection II-41
Livestock Watering Use II-46
Description of the Use II-46
Magnitude of Water Use and Trends II-46
Potential for Changes in the Projection II-46

Comparison Among Previous Projections II-51
Senate Select Committee on National Water Resources II-51
Projections by Wollman and Bonem II-52
The National Water Commission Projections II-52
Second National Water Assessment II-52
Comparison of the Demand Projections II-53

Summary II-56

Literature Cited II-57

References Cited—Unpublished II-59

Notes II-59

TABLE OF CONTENTS (Continued)

CHAPTER 3 -- THE SUPPLY SITUATION FOR WATER

Water Supply Quantity ....III- 1
Adequacy of Instream Flow ....III- 3
Optimal Habitat ....III- 3
Good Survival Habitat ....III- 3
Poor Survival Habitat ....III- 3
Instream Flow Rates and Regional Water Balances ....III- 4
Flooding ....III- 5
Summary ....III- 7

Water Supply Quality ....III- 7
Baseline Water Quality from Forests and Rangelands ....III- 8
Approaches to Improving Water Quality III-12
Point Sources III-12
Economic Impacts of Water Quality Improvements III-13
Nonpoint Sources III-14
Nonpoint-Source Pollution from Forests and Rangelands III-14
The Current Status of State Water Quality Laws Affecting Forestry Operations III-15
The South III-16
The North III-16
The West III-17
Summary III-17
Water Quality Improvements Since the Last RPA Assessment III-17
Summary III-18

Wetlands Supply Trends III-19
Wetlands Conversion Rates and Responsible Activities III-19
Projected Future Losses III-20
Other Uses of Wetlands Affected by Conversions III-25
Summary III-26

Summary III-27

Literature Cited III-28

References Cited--Unpublished III-29

Notes III-29

CHAPTER 4 -- COMPARISON OF PROJECTED DEMAND AND SUPPLY SITUATIONS

Plentiful Supplies and Shortages ....IV- 1
Plentiful Supplies ....IV- 9
Shortages ....IV- 9
Lower Colorado Region ....IV- 9
Rio Grande Region IV-12

TABLE OF CONTENTS (Continued)

Upper Colorado Region IV-13
Great Basin Region IV-13
California Region IV-15
Summary IV-17

Alternative Futures IV-17
A Future Where Demand is 20 Percent Higher in 2040 than Projected IV-18
A Future Where Demand is 20 Percent Lower in 2040 than Projected IV-18

Summary IV-26

Literature Cited IV-27

References Cited--Unpublished IV-27

Notes IV-27

CHAPTER 5 -- ECONOMIC, ENVIRONMENTAL, AND SOCIAL IMPLICATIONS OF THE PROJECTED SUPPLY AND DEMAND SITUATION

Implications of Water Shortages ....V- 1
Economic Implications ....V- 1
Economic Implications for California ....V- 1
Economic Implications for the Southern Rocky Mountains ....V- 2
Environmental Implications ....V- 3
Salinization ....V- 3
Groundwater Mining ....V- 5
Degradation of Fish and Wildlife Habitat ....V- 6
Social Implications ....V- 7
Population ....V- 7
Attitudes, Beliefs, and Values ....V- 7
Social Organization ....V- 8
Land Use Patterns ....V- 9
Summary V-10

Summary V-10

Literature Cited V-13

Notes V-13

CHAPTER 6 -- OPPORTUNITIES TO IMPROVE THE MANAGEMENT OF WATER AND RELATED FOREST AND RANGELAND RESOURCES

Ensuring Suitable Flows ....VI- 2
Opportunities to Manipulate Vegetation to Augment Low Flows ....VI- 2
Opportunities to Ensure Water Needed to Support Instream Uses ....VI- 3

TABLE OF CONTENTS (Continued)

Improving Watershed Condition ....VI- 3
An Increased Emphasis on Maintaining Water Quality ....VI- 4
An Increased Emphasis on Managing the Timing of Runoff ....VI- 4
An Increased Emphasis on Improving Riparian Areas ....VI- 5
An Increased Emphasis on Enhancing Soil Productivity ....VI- 5
The Opportunity for Improving Watershed Condition ....VI- 6

Nonstructural Flood Damage Reduction ....VI- 7
Flood Damages in Rural Areas ....VI- 7
Opportunities to Reduce Flood Damages ....VI- 7
Maintaining Soil Infiltration Rates ....VI- 7
Slowing Overland Runoff to Reduce Flood Peaks ....VI- 8
Summary ....VI- 9

Silvicultural Nonpoint Source Pollution Abatement Procedures ....VI- 9
Current Approaches to Implementing Abatement Procedures VI-10
Opportunities to Control Silvicultural Nonpoint-Source Pollution VI-10

Reversing the Trend in Loss of Wetlands VI-11
Legislative Changes to Conserve Wetlands VI-12
Appraisal Projections Provide Opportunities to Conserve Wetlands VI-13

Summary VI-13

Literature Cited VI-14

Notes VI-14

CHAPTER 7 -- OBSTACLES TO IMPROVING THE MANAGEMENT OF WATER AND RELATED FOREST AND RANGELAND RESOURCES

Water Prices in Transition ....VII- 2

In-stream Uses Have Low Priority ....VII- 3
A Clash of Priorities is the Obstacle ....VII- 4
Innovative Ways of Surmounting the Obstacle ....VII- 4
The "Nature Conservancy" Approach ....VII- 4
The "Multiple-Use" Approach ....VII- 5
Summary ....VII- 5

Watershed Condition Assessments Require Better Information ....VII- 5
Resources Inventory Data Must Be Clearly Presented ....VII- 6
Data Coverage is Incomplete at Places ....VII- 6
Where Coverage is Complete, Data is Unconsolidated ....VII- 6
Soil Survey work Should be Completed Expeditiously ....VII- 8

Private Landowners Lack Incentives to Use BMPs ....VII- 8
BMPs are Known ....VII- 9
Erosion Is An Externality ....VII- 9

Using BMPs Costs Money ....VII- 9
Some Landowners Lack the Knowledge to Implement BMPs VII-10
Summary VII-11

Current Laws Encourage Wetlands Conversion VII-12
Income Tax Encouragements VII-12
Property Tax Encouragements VII-12
Reducing the Incentives VII-13
Change the Income Tax Code VII-13
Change the Property Tax Code VII-13
Indirect Approaches VII-14
Summary VII-15

Environmental and Social Risks of Large-Scale Water Yield Augmentation VII-16
Environmental Impacts VII-16
Timber Cutting Will Increase VII-16
Stream Channel Integrity Will be Threatened VII-17
Other Environmental Impacts VII-18
Social Impacts VII-18

Summary VII-19

Literature Cited VII-21

References Cited--Unpublished VII-21

Notes VII-22

CHAPTER 8 -- IMPLICATIONS FOR WATER AND RELATED FOREST AND RANGE MANAGEMENT PROGRAMS

Question 1: What should the federal government do to ease potential future shortages of water and other watershed resources? ....VIII- 1
The Forest Service Mission in Easing Water Shortages ....VIII- 2
The Role of Other Government Agencies in Easing Water Shortages ...VIII- 2
The Real Problem is Water Prices ....VIII- 3
Recent Gains in Productivity Decrease Reliance on Irrigation ......VIII- 4
Freer Water Markets Will Help Reduce Projected Shortages ....VIII- 5
Social Preferences for Water Use Are Changing ....VIII- 6
Reversing Trends in Wetlands Losses ....VIII- 6

Question 2: What should be the mission of the national forests in the production of water and other watershed resources? ..VIII- 7
Maintaining and Improving Water Quality Will Become Top Priority ..VIII- 7
Ensuring Suitable In-stream Flows Is An Emerging Need ....VIII- 8
Managing Riparian Areas Will Become Increasingly Important ....VIII- 8
Long-Term Monitoring and Evaluation Sites Should Be Established ...VIII- 8

TABLE OF CONTENTS (Continued)

Question 3: Should policies for management of national forest watersheds vary among Regions? ....VIII- 9

Question 4: What should be the place of multiple-use as it relates to water and watershed management on national forests ...VIII-10

Question 5: What is the Forest Service mission in the production of water and watershed resources on nonindustrial private lands? VIII-11
- Private Landowners Need Assistance to Improve Water Quality VIII-11
- Private Landowners Need Assistance to Restore and Protect Riparian Areas VIII-12
- Private Landowners Need Assistance to Reduce Downstream Flood Damages VIII-12

Question 6: What is the mission of Forest Service research programs in the production of new information and technology needed for watershed and water quality management? VIII-13
- Cumulative Effects, Analyses Today and In The Future VIII-13
- Maintaining Land Productivity Is An Important Part of Watershed Research VIII-15

Literature Cited VIII-16

Notes VIII-16

LIST OF TABLES

Table No.	Title	Page No.
1.1	Watersheds by watershed condition class	I-11
1.2	Average net annual streamflow, by water resource region	I-23
1.3	Summary of reservoir storage capacity, including controlled natural lakes, in the United States and Puerto Rico	I-26
1.4	Distribution of reservoir storage, by water resource region	I-27
1.5	Degree of designated use supported by the Nation's waters	I-32
1.6	Average concentrations of heavy metals in street sweepings compared to shale	I-42
1.7	Geographic distribution of wetlands, by type	I-63
2.1	Total freshwater withdrawals in the United States for 1960 to 1985, by water use and source, with projections of demand to 2040	II- 6
2.2	Total freshwater consumption in the United States for 1960 to 1985, by geographic area and use, with projections of consumption to 2040	II- 7
2.3	Total freshwater withdrawals in the United States from 1960 to 1985, by geographic area and water source, with projections of demand to 2040	II- 8
2.4	Data used to project withdrawals and consumption	II-11
3.1	Expected annual stream outflows resulting from variations in precipitation levels and instream flow requirements, by water resource region	III- 2
3.2	Data for selected numbers of water quality from undisturbed forest and range watersheds in the United States, by division, province, and section	III- 9
3.3	Relationships among the distributions of community size, number of grants and value of grants for wastewater treatment plant construction, 1972 to 1982	III-13

LIST OF TABLES (Continued)

Table No.	Title	Page No.
3.4	Agricultural conversions of wetlands from the mid-1950s to mid-1970s	III-22
4.1	Generalized water budget for average and dry years, 1985 to 2040, by water resource region	IV- 2
4.2	Water consumption in the Lower Colorado water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040	IV-11
4.3	Water consumption in the Rio Grande water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040	IV-11
4.4	Water consumption in the Upper Colorado water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040	IV-14
4.5	Water consumption in the Great Basin water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040	IV-16
4.6	Water consumption in the California water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040	IV-16
4.7	Surpluses and deficits resulting from alternative demand futures, by water resource region	IV-19

LIST OF FIGURES

Figure No.	Title	Page No.
1.1	Average annual precipitation in the United States and Puerto Rico, 1951-1980	I- 3
1.2	Average annual runoff in the United States and Puerto Rico, 1951-1980	I- 5
1.3	Trends in groundwater withdrawals in the United States, 1960-1985	I-17
1.4	States reporting mine drainage as a special concern	I-34
1.5	States reporting nonpoint-source pollution as a special concern	I-37
1.6	States reporting control of toxic substances as a special concern	I-41
1.7	States reporting acid deposition as a special concern	I-48
1.8	Distribution of wetlands and their origins	I-62
1.9	States reporting wetlands loss as a special concern	I-65
2.1	Rates of increase in GNP, population, and water withdrawals, 1960 to 1985	II- 3
2.2	Increases in withdrawals, consumption, and related variables from 1960 to 1985	II- 5
2.3	Changes in net generation of electricity by fuel source, 1960-1985	II-11
2.4	Thermoelectric steam cooling, total freshwater withdrawals	II-12
2.5	Thermoelectric steam cooling, total freshwater consumption	II-16
2.6	Thermoelectric steam cooling, total freshwater withdrawals by region, 1960-1985, with projections to 2040	II-17
2.7	Thermoelectric steam cooling, consumptive use of freshwater by region, 1960 to 1985, with projections to 2040	II-18
2.8	Irrigation, total freshwater withdrawals	II-23

LIST OF FIGURES (Continued)

Figure No.	Title	Page No.
2.9	Irrigation, total freshwater consumption	II-24
2.10	Irrigation, total freshwater withdrawals by region, 1960 to 1985, with projections to 2040	II-25
2.11	Irrigation, consumptive use by region, 1960 to 1985, with projections to 2040	II-26
2.12	Municipal supplies, total freshwater withdrawals	II-29
2.13	Municipal supplies, total freshwater consumption	II-31
2.14	Municipal supplies, total freshwater withdrawals by region, 1960 to 1985, with projections to 2040	II-32
2.15	Municipal supplies, consumptive use by region, 1960-1985, with projections to 2040	II-33
2.16	Industrial self-supplied water, total freshwater withdrawals	II-35
2.17	Industrial self-supplied water, total freshwater consumption	II-36
2.18	Industrial supplies, total freshwater withdrawals by region, 1960 to 1985, with projections to 2040	II-37
2.19	Industrial supplies, consumptive use by region, 1960 to 1985, with projections to 2040	II-38
2.20	Domestic self-supplied water, total freshwater withdrawals	II-42
2.21	Domestic self-supplied water, total freshwater consumption	II-43
2.22	Domestic self-supplies, total freshwater withdrawals, by region, 1960 to 1985, with projections to 2040	II-44
2.23	Domestic self-supplies, consumptive use by region, 1960 to 1985, with projections to 2040	II-45
2.24	Livestock watering, total freshwater withdrawals	II-47
2.25	Livestock watering, total freshwater consumption	II-48
2.26	Livestock watering, total freshwater withdrawals by region, 1960 to 1985, with projections to 2040	II-49
2.27	Livestock watering, consumptive use by region, 1960 to 1985, with projections to 2040	II-50

LIST OF FIGURES (Continued)

Figure No.	Title	Page No.
2.28	Freshwater withdrawals, 1960 to 1985, with projections from other studies to the year 2000	II-54
2.29	Freshwater consumption, 1960 to 1985, with projections from other studies to the year 2000	II-55
3.1	Trends in the conversion of freshwater and saltwater wetlands, mid-1950s to mid-1970s	III-21

Chapter 1

THE CURRENT RESOURCE SITUATION FOR WATER IN THE UNITED STATES

Introduction

Several Federal agencies have historically had responsibilities for conducting assessments of the Nation's water resources. The U.S. Geological Survey (USGS), U.S. Army Corps of Engineers, and the U.S. Environmental Protection Agency (EPA) and its predecessor agencies, among others, have all conducted studies assessing the situation and future prospects for water in particular regions of the country.

Responsibility for national water assessments was assigned to the U.S. Water Resources Council (WRC) by the Water Resources Planning Act of 1965. With the demise of the WRC in 1981, several of the member agencies have attempted to take over parts of the WRC role and improve their own analyses. The U.S. Geological Survey began to publish an annual National Water Summary in 1984. The first three annual reports, Water-Supply Papers 2250, 2275, and 2300, have been used extensively in the preparation of this Assessment. In some cases, extended portions of text have been lifted from those reports, and in other cases, topics are presented in the same order. Similarly, EPA publishes biennial reports to Congress on the National Water Quality Inventory. Information from these reports has also been extracted for this Assessment. Other reports, mentioned in the endnotes, have also been extensively used.

The Forests and Rangelands Renewable Resources Planning Act of 1974 (88 Stat. 476, as amended; 16 U.S.C. 1601-1614) (RPA) became law, directs the Secretary of Agriculture to conduct an assessment of the Nation's forest and rangeland resource situation Covering all the renewable resources within the purview of the Forest Service. One of those is water. The RPA legislation also directed the Forest Service to follow two principles in conducting assessments. First, the assessments were to analyze the resource situation from a national perspective--including all ownerships, public and private. Second, the Forest Service was to use, to the extent practicable, information collected by other public agencies on the resources studied. This report faithfully follows that direction.

This report has 8 chapters, beginning with a broad overview of the current water resource situation in the United States. The extensive citations and endnotes are a "road map" directing readers to more detailed discussions of individual topics in the reports of other agencies.

One of the requirements of the RPA legislation is an analysis of prospective demands and supplies of each resource, looking ahead 50 years. Chapter 2

contains an analysis of historical trends in withdrawals and consumption and projections to 2040, based upon data from USGS and the Soil Conservation Service (SCS). Chapter 3 contains an analysis of historical trends in water supplies and projections to 2040, based upon generalized water budgets. The projections of demand and supply are results of new analyses by the author. It is important to recognize that the trends projected in these chapters are not in any sense "most likely." Rather, they portray what might occur if factors determining water resource management and use continue unchanged from those in effect since 1970. Obviously, projections of past trends will demonstrate conflicts between the level of demand and the level of supply projected to be available. A discussion of those conflicts is presented in Chapter 4 and the social, environmental and economic implications of those conflicts is presented in Chapter 5. Chapters 4 and 5 also contain analyses of some alternative future scenarios for water resources having the potential to alter the demand and supply projections which were based upon recent trends.

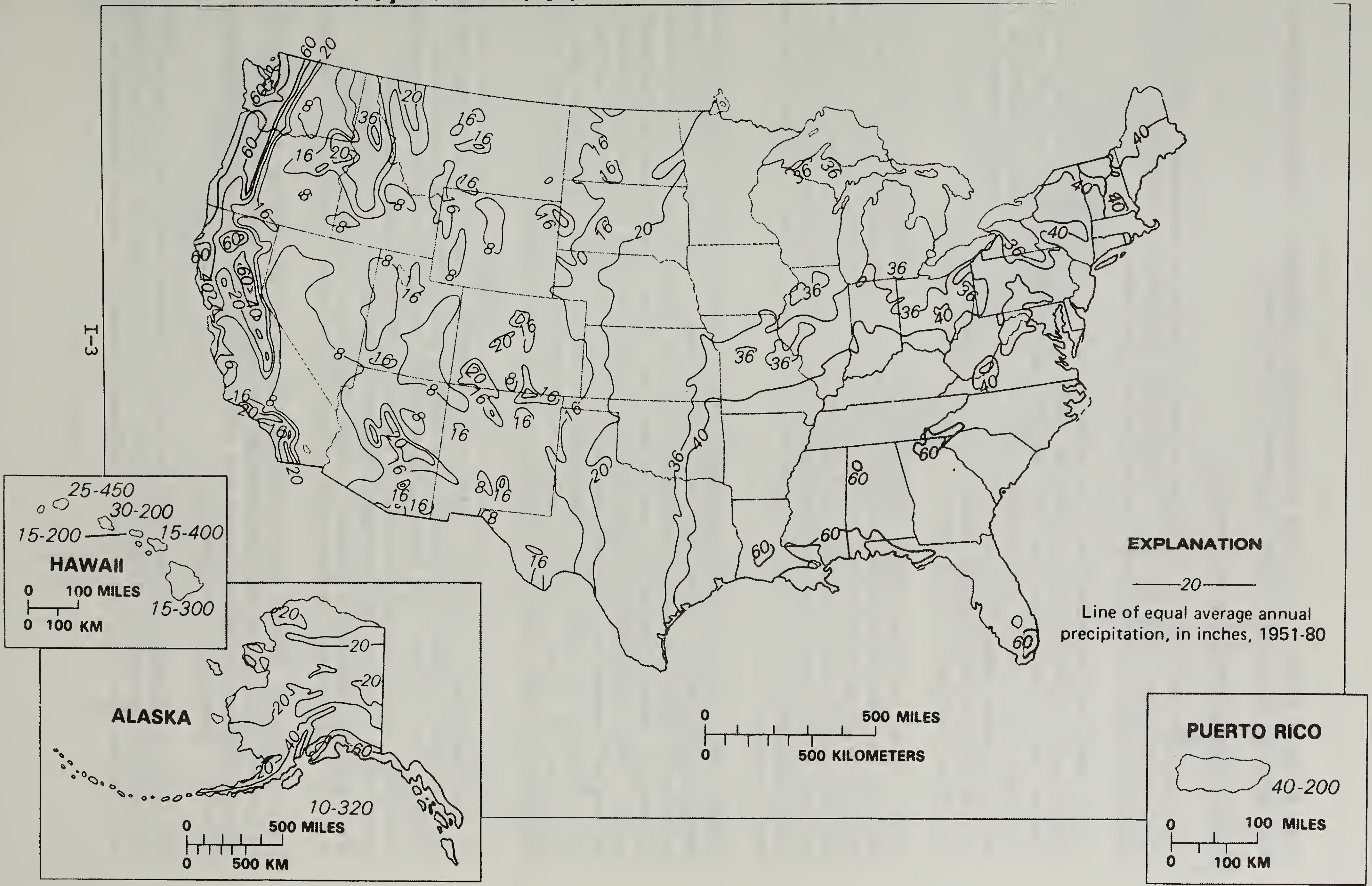
Differences between projections of demand and supply will not occur over time. The economy will function and prices will change to bring supply and demand into equilibrium. These adjustments, if not planned for in advance, can lead to undesirable consequences. Water resource users and managers have opportunities to alter use and management practices inherent in the recent trends to achieve a more desirable future water resource situation. These opportunities are outlined in Chapter 6. Similarly, there are some obstacles--economic, social, environmental, institutional, and regulatory--to taking advantage of the opportunities. These obstacles are discussed in chapter 7. Chapter 8 discusses the implications of these opportunities and obstacles on Forest Service resource management and research programs, providing guidance for agency strategic planning.

Precipitation Patterns[1]

The quantity of freshwater in rivers and streams is largely a function of the amount of precipitation. Nationwide, the average precipitation is about 30 inches per year, but precipitation patterns are quite variable. Average annual precipitation ranges from a few tenths of an inch in some desert areas of the Southwest to nearly 400 inches on some Hawaiian islands (fig. 1.1). East of the Great Plains, precipitation rates average 40 inches or more. In much of the West, however, precipitation rates are generally less than 20 inches annually.

After falling, precipitation moves in two general directions--directly back into the atmosphere or to streams. About two-thirds of the precipitation that falls either evaporates directly or is taken up by plants and transpired back to the atmosphere (when both are discussed together, the term used is **evapotranspiration**. The remaining third either runs over the soil surface to streams, perhaps causing erosion along the way, or percolates into the soil and moves through the soil profile to streams via groundwater flows. Underground geological formations containing water are called **aquifers**. Water withdrawn

Figure 1.1--Average annual precipitation in the United States and Puerto Rico, 1951-1980



from streams for use is called surface water withdrawal. Water withdrawn from aquifers via wells is called groundwater withdrawal.

Runoff-Precipitation Relationships

The land area drained by a single stream is called a **watershed**. When talking about watersheds, all the soil, vegetation, topographic and other factors that combine to make an integrated ecosystem are included.

It is important to understand the relationship between the amount of precipitation falling on a watershed and the amount of water in the stream flowing out of the watershed because many land management activities can affect the quantity of water in streams. The relationship is usually expressed in per-acre terms comparing precipitation and runoff. The average annual runoff is computed as the average annual stream flow volume at the bottom of a watershed divided by the number of acres in the watershed.

Runoff rates are also highly variable across the United States (fig. 1.2). Part of the runoff variation is due to precipitation variability.[2] But other factors, such as size, duration, and frequency of storms; climate, topography and geology of the watershed; and vegetation type and distribution in the watershed also have a large bearing on runoff-precipitation relationships. The interrelationships among all these factors is what makes watershed management challenging.

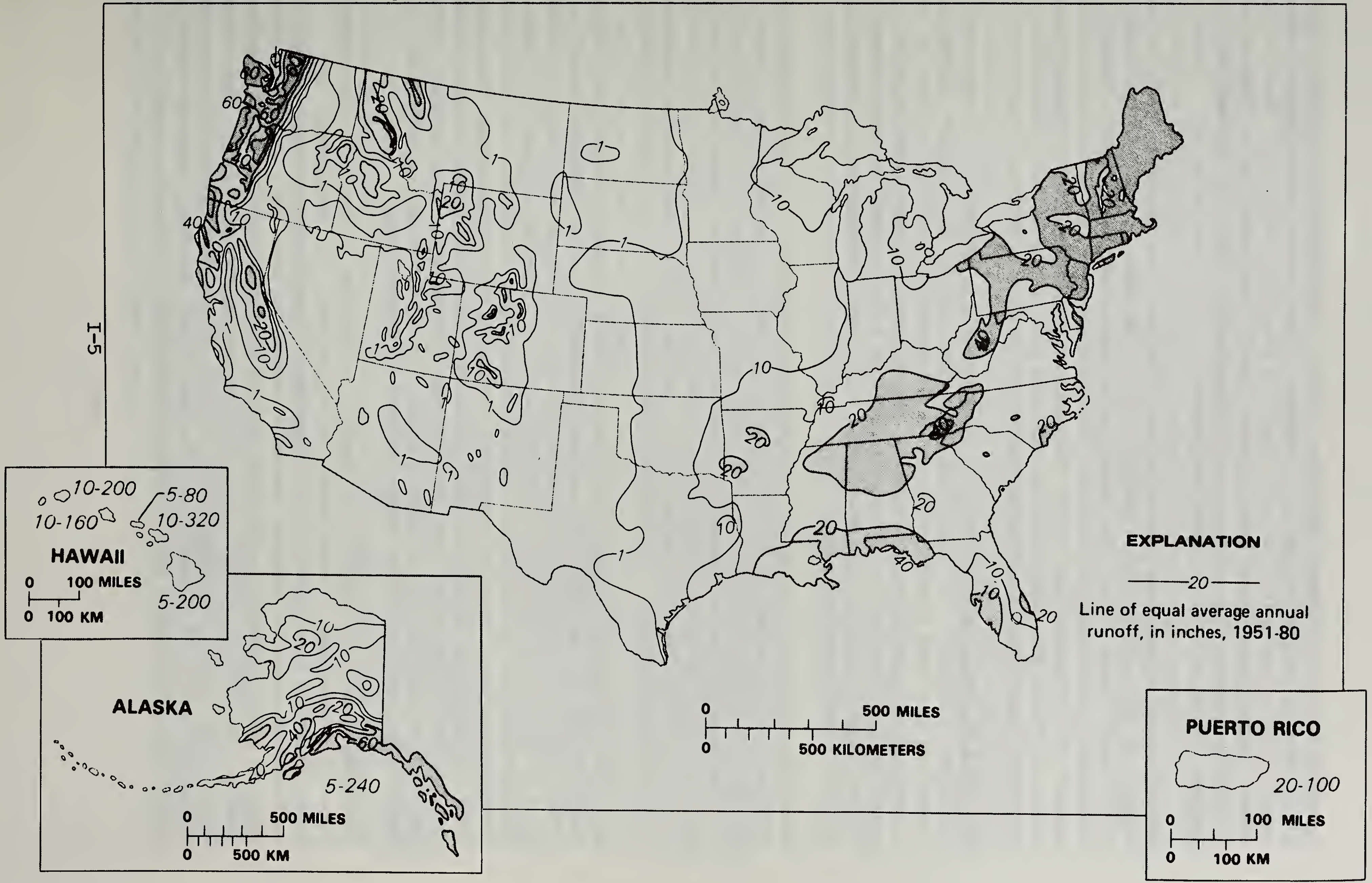
Either very high or very low runoff-to-precipitation relationships typically complicate managing forest and range ecosystems. High runoff-to-precipitation rates are typically associated with storms of high frequency and/or severe intensity, steep topography, and either very fine or very coarse textured soils. Very low runoff-to-precipitation relationships are associated with very infrequent storms or frequent ones with little rainfall per storm; storms that occur largely in summer when temperatures and therefore evaporation and transpiration rates are high; coarse textured soils; and soils where high evaporation rates concentrate salts in plant root zones.

A comparison of figures 1.1 and 1.2 reveals similarity in geographic patterns of precipitation and runoff. The highest annual runoff rates in the United States occur in Hawaii, typically exceeding 100 inches and occasionally reaching 320 inches. In southeastern Alaska and western Washington and Oregon, where the annual runoff exceeds 60 inches in many watersheds. Runoff in the northern and central Rocky Mountains, the Adirondacks, and southern Appalachians exceeds 40 inches. Large areas west of the Great Plains, especially those on the east side of mountains, have runoff of an inch or less.

The differences between precipitation and runoff are largely due to differences in evapotranspiration and groundwater recharge. Differences in evapotranspiration and recharge are due primarily to three related factors--climate, topography, and geology.

The Role of Climate--In semiarid and arid climates, most precipitation is lost to evaporation shortly after it falls. In some instances, rain can evaporate even before reaching the ground. Although potential evapotranspiration in

Figure 1.2--Average annual runoff in the United States and Puerto Rico, 1951-1980



semiarid areas may exceed 70 inches, actual evapotranspiration rates are much lower because precipitation is so scarce. Thus, actual evapotranspiration nearly equals precipitation and runoff is therefore very low. East of the Great Plains where the climate is more humid, precipitation is typically 15 to 20 inches greater than average evapotranspiration rates of between 20 to 40 inches. Thus, runoff volumes are greater.

Runoff amounts from equal annual precipitation rates vary depending on the nature of the precipitation events. Given the same annual precipitation total, more runoff comes from a few large storms than many small ones. Runoff is also affected by the timing of storms. Watersheds where storms are more common in summer will produce less runoff than watersheds where storms are more common in winter. The higher temperatures and more active vegetation respiration present in summer leads to more evapotranspiration than in winter.

<u>The Role of Topography</u>--Watershed topography also affects the amount and character of runoff. A watershed with steep slopes at a higher elevation receiving the same precipitation as a watershed with gentler slopes at lower elevation will produce more runoff. The steeper slopes allow water to flow more rapidly through the watershed, so less time exists for evapotranspiration. Higher elevations are also associated with lower temperatures, decreasing the rate of evapotranspiration.

Watershed topography also has a significant influence on runoff because it influences the **amount** of precipitation received. Precipitation is usually greater at higher elevations than lower ones. Further, the location of mountains relative to prevailing storm paths is another topographic factor. As an air mass crosses a mountain range, most of the precipitation falls on the side from which the storm approached. In the United States, this windward side typically faces west. The leeward side is said to be in the **rain shadow**.

<u>The Role of Geology</u>--Geology influences runoff largely through its influence on soil texture and permeability. Coarse-textured soils encourage rapid infiltration of precipitation and rapid percolation to aquifers. Groundwater flow in such situations is relatively rapid. Fine-textured soils impede infiltration and percolation, thereby encouraging overland flow to streams. Sedimentary rock, such as limestone, generally store more water than igneous rock. Older rock formations tend to be more fractured than younger formations, and so they store more water than younger formations. Consequently, watersheds based on relatively new igneous formations will have more runoff than watersheds based on older, more sedimentary formations.

Groundwater storage quantity is largely a function of geology--the porosity of the rock formations. Groundwater is replenished, or "recharged," by percolation of precipitation and by seepage from stream channels. Where porous rock strata intersect stream channels, water can move back and forth between streams and groundwater. Whenever stream levels are higher than groundwater levels, the streams recharge the aquifer in the porous strata. When stream levels drop lower than groundwater levels, groundwater seeps into the streams and becomes part of streamflow. The ability of aquifers to store runoff is so great that groundwater seeping into streams may provide an average of 40

percent of the annual streamflow in some areas and nearly all the flow during periods of lowest flow when direct runoff from precipitation is nil.

Annual runoff from a watershed is the net result of all these natural influences interacting with the human influences of watershed use and management. For watersheds where natural influences predominate, the average runoff over a long period of years (to eliminate short-term climatic variations) is a reliable indicator of the long-term renewable supply of water. For watersheds where human influences predominate, they are a much stronger determinant of the long-term renewable supply.

Seasonal Runoff and Streamflow Variations

Within a given watershed, streamflows vary by the time of year. A period of high flows is normally followed by a period of low flows. The timing of the high and low flows differ by watershed location, and is a function of seasonal distribution of precipitation and temperature.

Where temperatures are seldom below freezing for more than a few days at a time, the monthly distribution of runoff streamflow corresponds closely to the monthly distribution of precipitation. For example precipitation and runoff both are highest in winter in watersheds along the Pacific Coast.

Where temperatures are below freezing for extended periods, winter precipitation accumulates as snow and ice until temperatures climb back above freezing and melting occurs. If snow and ice accumulate only in a limited area high in the watershed, the effect of the melting water on streamflow will be minor. If only small amounts of snow and ice accumulate due to the occurrence of several freeze-thaw cycles during the winter, or if wintertime precipitation is low, little water will be stored as snow and ice and melting runoff will have only a minor effect on streamflow. These are the normal situations in mountain watersheds across the United States at southerly latitudes. But if wintertime precipitation is high and below-freezing temperatures occur for extended periods, then runoff storage as snow and ice is large and the potential for a major increase in streamflow in the spring and summer is high.

The character of the temperature warmup in spring after an extended period below freezing also affects streamflow variations. If the watershed is uniformly covered with snow and ice, streamflow will rise rapidly. Floods are likely in this situation. If the warmup is gradual and mild, then the snow and ice will melt slowly and streamflow will be higher for a longer period, albeit at a lower maximum daily flow. Flooding is less likely with this temperature scenario.

Annual Flow Variations—Droughts and Floods

Annual variations in runoff from a watershed are caused by changes in weather patterns and precipitation. Runoff variations will be highest in arid and semiarid watersheds because a small change in precipitation has a large effect on runoff. In some other watersheds, the varying intensity of storms has a large effect on streamflow. Hurricanes along the Gulf Coast can cause severe increases in streamflow when they occur.

Droughts--The definition of a drought varies, depending upon the intended use of water in streams. In short, a drought is the lack of precipitation for an unusually long period of time, with concomitant decline in runoff to a level significantly lower than the average annual low flow. The effects of a drought are a function of the severity, duration, and geographic extent of the precipitation deficiency; whether water supplies are drawn from streams, impoundments or aquifers; and the type and magnitude of water use.

Dryland (without irrigation) farming crop yields will decline if rain does not occur for a few consecutive weeks during the growing season. Municipal water supplies that depend upon streamflow and have limited storage will not be adequate unless replenished by runoff every few weeks. In semiarid watersheds, livestock often depend upon small reservoirs--stock ponds--that require replenishment at frequent intervals. Water users in these situations would consider a relatively short period of time without rainfall to be a drought.

If water users draw supplies from large rivers or major impoundments holding the equivalent of two or three years' annual flow, a critical drought is caused only by precipitation deficits extending over several years or droughts that are exceptionally widespread. During droughts of this nature, usable water in both reservoirs and impoundments becomes progressively depleted until the usual rates of water withdrawals cannot be made.

Drought severity is normally expressed as a probability of a monthly low flow being attained. A streamflow drought is said to occur when streamflow for a 30-day period or longer is unusually deficient. An "80 percent" drought means that an average monthly flow higher than that observed is expected in 8 of 10 years. In the water supply analysis of Chapter 3, the definition of a "dry year" is an 80 percent drought.

The effects of major droughts this century, especially multi-year droughts, have been devastating. The "Dust Bowl" of the 1930s stemmed from a multi-year drought in the Great Plains. The effects of the decline in waterfowl habitat from that era are still being felt in current waterfowl populations. Other notable multi-year droughts occurred in the 1950s (Thomas and others 1962, Nace and Pluhowski 1965) and 1970s (Matthai 1979).

Floods--A flood is any streamflow so high that it overtops the streams natural or artificial (levee or dike) channel in a particular reach of stream. Floods range from fairly common annual high flows that barely overtop the natural stream banks to rare events that crest well above natural channels. Floods are usually compared according to the heights of their crest above some reference point or the probability that flows of a given size can be expected. For example, a "100-year flood" is a flow that has a one-in-one hundred chance of being exceeded in any given year.

Floods along the coast usually result from high tides and storm surges, such as expected with the passage of a hurricane. Floods along inland streams and rivers usually result from intense rains, rapid snowmelt, or a combination of the two. The largest floods usually are caused by intense rainfall occurring in several adjoining watersheds with the runoff peaks arriving simultaneously

at the confluence of tributaries from the watersheds. Towns are often located at such confluences. The second most common cause of severe floods is the combination of rapid snowmelt and heavy rainfall. Such a situation occurred in the Colorado River basin in 1984 when abnormally heavy snowpack followed by unseasonably warm temperatures caused a near-record runoff that began about May 20, 1984. Heavy rains in part of the basin led to peak flows more than 1.5 times the estimated 100-year flood level on the Uncompahgre River at Delta, CO.

Floods can also be created or exacerbated by other watershed factors. These include mountain glaciers, unstable soil and rock formations, earthquakes, volcanic activity and the presence of impoundments in combination with the above. For example, the flood resulting form the June 5, 1976 collapse of Teton Dam in the Snake River drainage, ID, has been attributed to porous fractured rock formations used to anchor an abutment and that underlay the dam itself.[3] Mud flows resulting form the combination of glacier melt and volcanic explosion on Mount St. Helens in 1980 caused great damage--even obstructing the shipping channel in the Columbia River 70 miles from the volcano. Even after receding, the mud left along the Toutle and lower Cowlitz Rivers so constricted the channels that even the average annual high flow could have caused severe over-bank flooding (Foxworthy and Hill 1982).

About 6 percent of the lower 48 states are prone to flooding. Nearly 21,000 communities have flood problems. Floods cause about 10 times more deaths each year than any other natural hazard. During 1985, the economic loss due to flooding was about $500 million--the lowest amount since 1971. Despite these losses, floods also confer benefits. Because a large part of the annual runoff from some streams occurs during floods, they play a major role in replenishing reservoirs and are important elements in the management of water supplies.

Intensive land use has drastically modified flood plains and streamflow characteristics form their natural condition 400 years ago. It has now been clearly established that virtually every change in land use alters to some extent the water quality and flow regime of a watershed. This is especially true of use changes in the floodplain. Because of the high cost of structural flood control measures and their attendant undesirable side effects, the emphasis in flood protection has shifted to non-structural measures. These include improving flood forecasts, installing community flood warning systems, zoning or limiting land uses in flood-prone areas, and publicizing flood hazards. The USGS, the U.S. Army Corps of Engineers, the Federal Emergency Management Agency (FEMA), SCS, and various state agencies have all cooperated to develop and implement these flood control measures.

Despite the non-structural measures and the benefits they have conferred, the long-term trend in flood damages is increasing. Much of the increase in economic losses can be attributed to continuing encroachment onto the floodplain. In spite of the risk, people continue to be attracted to floodplains by their many advantages--flat land, desirability for transportation routes, access to water, and superior agricultural soils. Once uses are established on the floodplain, governments try to control flood damages by building dikes, levees, dams, and other flood control structures. Because these structures successfully reduce damages from small to moderate floods, additional incentives exist to develop the floodplain further. Thus,

when a flood occurs that overwhelms the flood control structures, the resulting damage is often much greater than if development had been limited by periodic, small-scale flooding.

Watershed Condition

What happens to precipitation after it falls is affected by the intensity and duration of the rainfall as well as the climate. Short, light rains in arid climates evaporate nearly completely; while long intense rains during a hurricane largely become runoff. However, the nature and condition of the soils and vegetation where the precipitation falls also play an important role in the amount of precipitation evaporating, infiltrating, or running off the site. Dense vegetation intercepts precipitation and promotes evaporation and transpiration; scattered vegetation, perhaps due to recent disturbance by fire or management practices, intercepts less water so more is available for infiltration or runoff. Sandy soils and flat topography promote infiltration; clayey soils and steep topography promote runoff.

Human influences that modify the soil and vegetative patterns and distributions in watersheds alter the natural watershed responses to precipitation. For example, urban development paves and erects roofs over land making it impervious to rainfall; less infiltration and more runoff is the result. Removing forest cover or plowing prairie grasslands reduces evaporation and exposes soil to the erosive influences of runoff. Because the influence of mankind's use of the land and vegetation is pervasive in many watersheds, managing the soil and vegetation in the watershed is a key factor in managing the quality and quantity of water draining out of the watershed.

The National Forests were originally established "...to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of the citizens of the United States..."[4]. The central idea was to manage the forested ecosystem to maintain favorable (in terms of both quantity and quality) water flows and to maintain the productivity of the soils to produce vegetation, such as forage and trees. These goals for forest and rangeland management have been embodied in the concept of **watershed condition**. Watershed condition is a description of the relative health of a watershed. It reflects the stewardship role of the Forest Service and is measured against management objectives in terms of factors affecting favorable conditions of flow and soil capabilities.

Maintaining favorable conditions of flow refers to the behavioral characteristics of a watershed, described in terms of its ability to sustain water quality, quantity, and timing necessary to support water-dependent ecosystems, instream uses, and downstream withdrawals of water. Included in this concept are managing the land and land uses affecting water quality and quantity as well as managing the natural and manmade stream channels carrying flows to users. Also included is managing water in streams and associated fauna as well as groundwater flows.

Maintaining soil capability refers to the inherent capacity of a soil to support growth of specific plants, plant communities, and sequences of plant

communities. Included in the concept of plant communities and the succession of communities are the associated fauna for those communities.

The concept of watershed condition provides an excellent basis for assessing the resource situation for water and related land resources. The condition of watersheds nationwide has been evaluated for this report. A sample of watersheds of 40,000 to 180,000 acres in size in each Forest Service Region was determined to be indicative of all watersheds in the United States. Each watershed was placed in one of three watershed condition classes, described below, and a regional summary prepared describing the percentage of watersheds in each part of the United States that are in each condition class, table 1.1.

Table 1.1—Watersheds by watershed condition class, 1987

Region	Condition Class I	Condition Class II	Condition Class III
	percent		
North	15	60	25
South	20	67	13
Rocky Mountains	27	49	24
Pacific Coast	36	45	19
U.S. Total	28	50	22

Class I: Regimen Attainment

Watersheds in this class provide a robust basis for sustained production of goods and services. The watershed management is such that no long-term changes are occurring even when major precipitation events occur. These watersheds represent an attainable, desirable condition. They are in dynamic equilibrium as evidenced by a stable drainage network. The response of the watershed to use is accommodated by the current channel network density, size, and process.

In Class I watersheds, production of goods and services can be sustained with low risk of deterioration in watershed condition. These watersheds are most prevalent in the Pacific Coast and Rocky Mountain regions. Legislation and regulations governing use of land designated wilderness have had a major influence in keeping watersheds in Class I condition because they have proscribed many surface-disturbing uses, such as off-road vehicle use and timber harvesting. Much of the roadless land not designated wilderness is in watersheds having such rugged terrain that land-disturbing activities can only occupy limited areas if they can occur at all.

Class II: Special Emphasis

Watersheds in this class are not attaining the requirements for Class I, but do not require capital investments to restore Class I watershed conditions.

The majority of the watersheds surveyed are in Class II. Watersheds in this class require special consideration of their soil and vegetation characteristics when resource management plans are prepared because the soils in these watersheds have a high potential for erosion and significant risks to water quality exist--in short, improper or insensitive management will quickly lead to major soil or water problems and deterioration to Class III conditions.

Many of the Class II watersheds are currently performing to management objectives. There are four reasons why most watersheds are in Class II. Some watersheds are sensitive to specific land-disturbing activities, such as mining, off-road vehicle driving, or timber harvesting. Others watersheds are sensitive to the cumulative effect of activities. Cumulative effects can result from activities whose per-acre impact may be light, but whose total effect has overwhelmed the watershed's ability to tolerate the use because the use is widespread. Also in Class II are watersheds whose use potential is inherently limited due to fragile soils and stream channels, and watersheds that have not reached a dynamic equilibrium in their recovery from past abuses.

The South and North have the greatest number of watersheds in Class II primarily because of high water tables, severe erosion hazards, and a lower percentage of wilderness and other unroaded lands than in the Pacific Coast and Rocky Mountain regions. High water tables reduce trafficability. Lands with limited potential for maintaining favorable water flows are most common in the Rocky Mountain region, comprising the bulk of Class II watersheds there. Watersheds in Class II in the Pacific Coast region are subject to landslide hazards, primarily in high rainfall areas. Because of the steep terrain in the Rocky Mountains and Pacific Coast regions, watershed condition concerns often relate to location of transportation corridors and protection of riparian areas. The steep terrain also increases the risk to downstream areas of flooding because of rapid runoff. Therefore, any activities that disrupt infiltration and increase overland flow are of particular concern in Class II watersheds in these regions.

The factors affecting watershed condition and risks to sustaining condition vary greatly among and within a region. Because such a large proportion of watersheds are within Class II, the opportunities to improve conditions through integrated resource management are greater than through direct capital investments. While both approaches cost time and money, the process of integrating resource management is often more affordable, per acre, and line officers often have sufficient authority to proceed with it. However, it requires more professional skill and creativity to implement. For example, the advice from a team of people from a variety of scientific disciplines is essential for integrated resource management. The planner, then, must have the knowledge and ability to (1) assimilate all the advice and fabricate a single plan covering all resources that simultaneously takes advantage of synergy among resources and mitigates adverse consequences on other resources and (2) sell the plan to the manager on its merits.

Class III: Investment Emphasis

Watersheds in this class require technologically and economically feasible capital investments to restore watershed conditions to a level consistent with

resource management goals. Determination of feasibility must consider environmental, social, and economic desirability. These land treatments and structural measures are necessary to provide an improved watershed equilibrium, moving the watershed to Class II condition. Once in Class II, non-structural measures--integrated multiple-resource activities--are used to attain Class I status.

Nationwide, about 22 percent of all watersheds need capital investments to restore water quality, quantity, timing, or soil productivity to acceptable levels. This does not mean that 20 percent of the land or channels are in Class III condition. A relatively small area can disrupt an entire watershed system by its contribution of sediment, mine waste, increased flow volume, or other impacts that influence soil productivity and favorable conditions of water flow.

The South has the fewest watersheds needing capital investments to restore watershed conditions to levels consistent with management goals, table 1.1. In the other regions, between one-fifth and one-fourth of the watersheds need capital investments. At the beginning of the 20th century, many of the watersheds across the South were badly deteriorated by abusive farming practices of the 1800s. After agriculture was abandoned on the watersheds, many seeded naturally to southern pines. Reforestation has restored the watershed condition to Class II in most cases.

A classic example of the kinds of capital investments necessary to restore Class II conditions is the Yazoo-Little Tallahatchie (Y-LT) Project in north central Mississippi. The watersheds of the Yazoo and Little Tallahatchie Rivers contain incredibly erodible soils, many of loessal origins. By the 1930s, after being farmed for a century, the soil capability to produce crops was exhausted. Due to a lack of vegetation to serve as ground cover, precipitation caused massive and widespread gully erosion. In 1946, the Forest Service and SCS began a joint program to rehabilitate the watersheds. The project area covered 4.2 million acres in 19 counties. The four major goals of the Y-LT Project were to reduce floodwater and sediment damages; to promote proper land use; to stabilize stream channels; and to improve the local economy in north central Mississippi (Guttenberg and Pleasonton, 1961). In the early 1960s, it was the largest individual land and water management program in the United States. The Yazoo and Little Tallahatchie watersheds were divided into 54 sub-watersheds. Farm conservation plans based on land capabilities were developed with the assistance of SCS District personnel. Following approval of the conservation plans, financial assistance was provided to plug gullies and plant trees. On "critical" areas (exposed soil, slopes over 8 percent, gully erosion present, and downstream damage occurring), the entire cost was paid by the government. On other areas, free tree seedlings were provided and the cost of planting and control of competing vegetation was shared between the government and the landowner. Today, the watersheds of the Yazoo and Little Tallahatchie Rivers support productive stands of southern pine with sufficient volumes to attract new wood processing industries to the north central Mississippi town of Grenada. Some areas are currently being harvested, providing jobs and income to the local economy. Of course, harvesting must be done carefully to avoid creating new erosion and replanting is essential. The Y-LT Project is an example of how direct capital investments can be used to

rehabilitate Class III watersheds and move them to Class II conditions. Its success has been the impetus for more recent watershed rehabilitation and improvement programs, such as the Soil Bank Program of the 1950s and 1960s, and the Conservation Reserve Program of the 1980s.

Summary

The condition of watersheds strongly influences both the quantity and quality of water available for use. The current status of the Nation's watersheds is less than ideal--one-fifth need capital investments and one-half need especially careful management to attain long-term land and water resource management goals. Consequently, the quantity and quality of water currently available for use is also less than ideal. The current situation for water use from a quantity perspective is examined next. Following that, the Nation's water quality situation is reviewed and then the wetlands situation. These discussions of rainfall and runoff volumes, watershed condition, quantity and quality of water currently used, and wetlands condition provide the necessary background to assess future demands and supplies of water in Chapters 2 and 3.

Quantity of Water Available for Use

The renewable water supply of the coterminous United States amounts to about 1.4 trillion gallons per day. Even though total offstream withdrawals of surface water nearly doubled from 1960 to 1985, withdrawals still remained only 21 percent of the renewable supply in 1985. Despite major droughts, such as the one in the eastern United States in 1985 and the one emerging in 1988 as this report was being prepared, and despite chronic water shortages in some localities, the Nation is not "running out" of water. Periods of drought will be followed by periods of above-normal precipitation and runoff in the future as in the past. Most of the concerns about water shortages arise because of uneven distribution of the water in relation to the regional and seasonal distribution of water demands; concerns also arise because of increasing demand for existing supplies and related difficulties in distribution. In some situations, changes in engineering, management, or institutional procedures can improve the situation.

Although the available supply appears unlikely to change appreciably in the near future, estimates of that supply may not be very accurate because there is no objective way of selecting a representative period of record that includes the full range of possible variations. Moreover, even if the long-term average supply could be closely estimated, the actual supply over a specific future period probably will deviate from that average. One of the problems facing water resource planners is the inability to define accurately the amount of water available, and this uncertainty should be considered in developing and allocating water resources.

Instream versus Offstream Uses

Water has value both instream and offstream. Instream uses of water include navigation, fish and wildlife habitat, hydropower generation, recreation activities, and dilution of wastes. Instream uses usually require some minimum

flow rate, thus, they compete directly with offstream uses, which reduce instream flows. For example, instream flows must not fall below some minimum rate if navigation is to continue. Some instream uses can tolerate reductions below the minimum essential level for a short period of time with little or no long-term effect on benefits. For example, navigation can be suspended for several weeks during exceptionally low flows and start up again when sufficient water is available without incurring any long-term reduction in navigation benefits. Wildlife and fish habitat, on the other hand, can suffer devastating long-term losses from several weeks of abnormally low flows. Of the instream uses mentioned above, fish and wildlife habitat is the most sensitive: long-term damage results from low flows.

Offstream uses are also called diversions or withdrawals because water is withdrawn or diverted from the stream channel and transported to the point of use. Offstream uses include cooling power generators (thermoelectric steam cooling in USGS parlance), irrigation, industrial and commercial use, and potable use. For all uses except irrigation, most of the water is returned to the stream following use, usually with some aspect of its quality (temperature, dissolved solids, other chemical constituents, sediment load) changed. The part of the water withdrawn from the stream that does not return to the stream is "consumed"--principally by vegetation which subsequently transpires it back to the atmosphere--or evaporated during use. In Chapter 2, the trends in demand for water will be discussed in terms of withdrawals and consumption by six main uses.

In some parts of the country, water is withdrawn from watersheds with large flows and transferred by pipes or aqueducts to watersheds where demands for withdrawals exceed available flows. For example, water from streams in central and northern California and from the Colorado River are currently transferred to southern California. Such interbasin transfers of water are equivalent to a 100 percent consumptive use from the perspective of the watersheds where the water originates.

Pumping groundwater is also considered an offstream withdrawal of water. Where a porous stratum containing groundwater intersects a stream bed, pumping water from the aquifer can not only intercept water that would otherwise seep into the stream channel, but if sufficiently intensive, can induce water to flow from the stream into the aquifer. Reductions in instream flows occur some time after the onset of pumping, and unless the wells are very near the stream, usually do not coincide with the times of peak withdrawals from the streams.

In this brief introduction, the major categories of use for streamflow--groundwater withdrawals, instream use, and surface water withdrawals--have been outlined. Each will now be discussed in additional detail to provide a clearer picture of the current resource situation.

Groundwater Development[5]

The volume of groundwater in storage in the upper half-mile of the Earth's crust within the coterminous United States has been estimated to be on the order of 50,000 cubic miles (55,000 trillion gallons). Some of this water is highly saline and unsuitable for most uses. The recharge--in effect, the rate

of flow through the groundwater system--has been estimated to be on the order of 1 trillion gallons per day. A large percentage of this flow moves through very shallow aquifers which presently discharge to streams without reaching major aquifers. Only a portion of this shallow recirculation could be recovered by wells.

The pumping rate of fresh groundwater in the United States in 1985 was approximately 83 billion gallons per day (bgd)--on the order of 8 percent of the estimated daily flow through the Nation's groundwater systems. From a national perspective, the groundwater resource is not overdeveloped. But problems do exist in many localities.

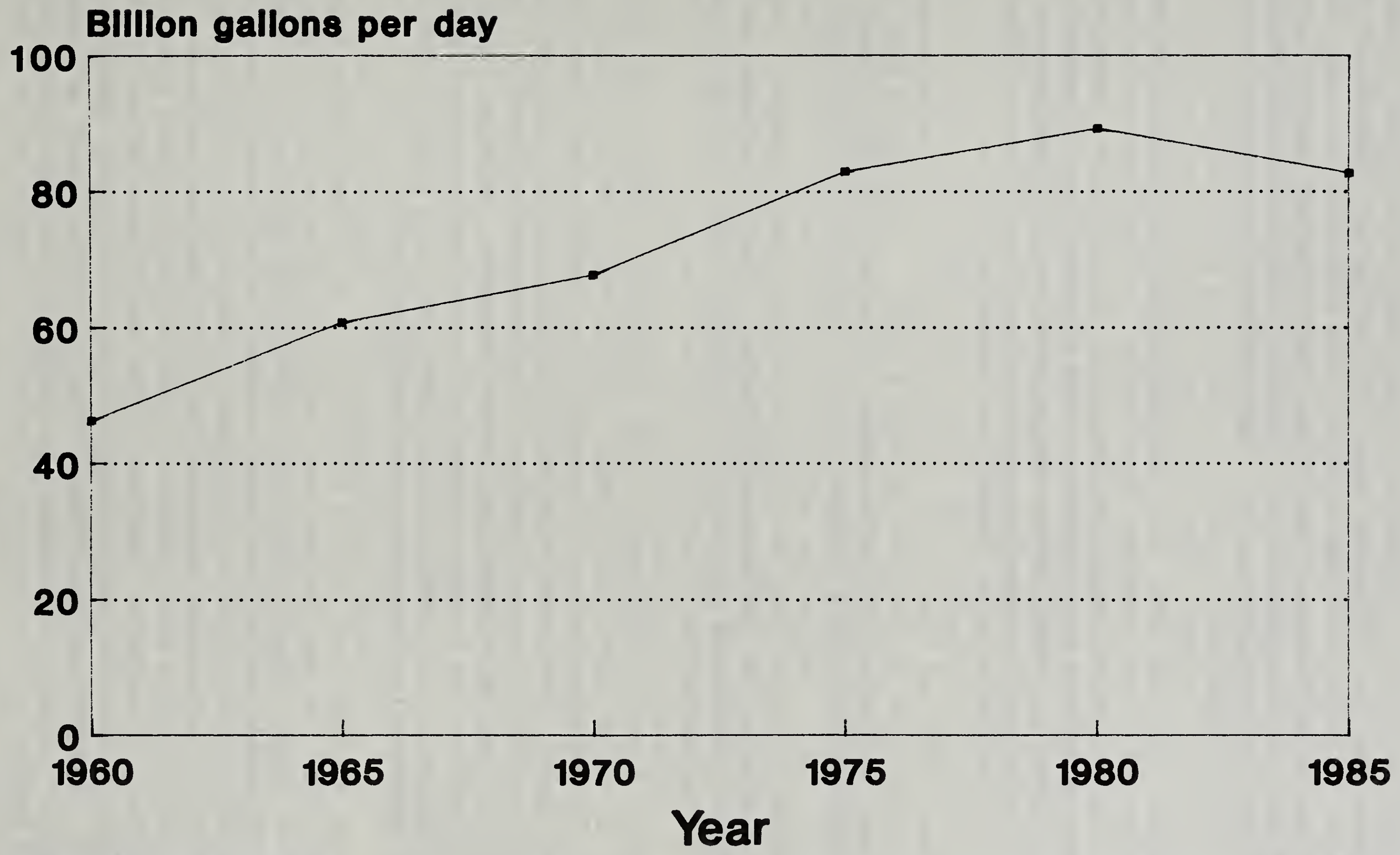
The total groundwater withdrawn in 1985 represented about 24 percent of the total freshwater withdrawals in the United States. The largest single use is for irrigation--slightly more than 56 bgd. Although irrigation is the largest withdrawal, roughly half the population in the United States relies upon groundwater for potable supplies. About two-thirds of the in groundwater withdrawals in 1980 were concentrated in eight states: California (21 bgd); Texas (8 bgd); Nebraska (7.2 bgd); Idaho (6.3 bgd); Kansas (5.6 bgd); Arizona (4.2 bgd); Arkansas (4 bgd); and Florida (3.8 bgd). Nine states use more groundwater than surface water--Arizona, Delaware, Florida, Hawaii, Kansas, Mississippi, Nebraska, Oklahoma, and Texas.

The pumping rate for groundwater increased steadily from 1960 to 1985 (fig. 1.3). Some of the factors responsible for the increase include a significant expansion of irrigation in the humid East as well as the West, particularly through the use of center-pivot irrigation systems; water supply requirements of growing urban areas, particularly in the South and Southwest; water demands associated with energy production; a desire to establish drought-resistant supplies; objections to the construction of surface reservoirs; and objections to exporting water from one watershed to another. The quantity of groundwater withdrawals in 1985 represents the first reduction in withdrawals reported in the past 3 decades. The nearly 10 percent reduction is more than a data anomaly--it reflects some changes in the factors contributing the increase since 1960.

<u>Aquifer declines</u>--Aquifer declines have occurred in many areas since development began. But not all declines are of major concern. In most areas, the declines have occurred at depths substantially deeper than the water table. But because of the artesian processes involved, the declines do not represent the loss of large quantities of water from storage.

In some areas, however, the declines are serious. For the High Plains region of Kansas, New Mexico, Oklahoma, and Texas, and for the alluvial watersheds of southern Arizona, the aquifer declines have resulted in a significant lowering of the water table. In these areas, very large volumes of water have been withdrawn, and continue to be withdrawn from storage. In some parts of central California, substantial withdrawals of groundwater in local areas have largely dewatered porous strata, leading to compaction of the strata and surface land subsidence. A description follows of the severity of the situation in the four areas most heavily affected.

Figure 1.3--Trends in groundwater withdrawals in the United States, 1960-1985



Source: USGS Circulars

The High Plains—The High Plains encompass 174,000 square miles in northwestern Texas, the Oklahoma panhandle, western Kansas, Nebraska, and the eastern fringes of Wyoming, Colorado, and New Mexico. A rapid expansion in groundwater withdrawals for irrigation began in the southern High Plains in the early 1940s. Irrigation spread to the middle High Plains in the 1950s and to the northern High Plains in the 1960s. As irrigation spread, so did groundwater withdrawals. In 1949, about 2 million acres in the High Plains was irrigated by 1303 billion gallons. By 1980, 5865 billion gallons were pumped to irrigate 13 million acres.

Between 1940 and 1980, 68.4 trillion gallons of groundwater were withdrawn for irrigation in the southern High Plains. It has been estimated that 43 percent of this volume was water from storage, 45 percent was recycled irrigation water percolating back to groundwater, and the remaining 12 percent was diversion of groundwater as water tables dropped that would otherwise have drained into streams and by increased aquifer recharge from streams. Floods in the early 1970s contributed significantly to recharge.

Between 1950 and 1980, 31.3 trillion gallons of groundwater were withdrawn for irrigation in the central High Plains. Withdrawals from storage were 57 percent, recycled irrigation water 39 percent and groundwater diversions/recharge 4 percent. The 1970 floods provided little recharge here.

Between 1960 and 1980, 34.2 trillion gallons of groundwater were withdrawn for irrigation in the northern High Plains. About 14 percent was withdrawn from storage, 36 percent by recycled irrigation water, and 50 percent from diversions/recharge.

Several factors contribute to the differences between the northern High Plains and the other High Plains areas. In the northern High Plains, more surface-water irrigation occurs. Groundwater recharge rates before irrigation development began were also higher in this area. Land use changes have also had an effect. As more land was brought under cultivation, increased infiltration of rainfall led to more recharge. Because rainfall is more prevalent in the northern High Plains, more recharge occurs there. Finally, irrigation in the northern High Plains requires a much lower rate of pumping per square mile than in the southern High Plains.

In the southern and central High Plains, withdrawals from storage have been so great that the aquifer has been dewatered by more than 50 percent in over 3,500 square miles. This decline has affected irrigation in two ways. Increased energy costs are required because water is now pumped from a greater depth. Second, as the saturated thickness of the strata has declined, yields of individual wells have also declined, so additional wells must be drilled to provide the same water volume. These economic impacts have led to the beginning of a gradual decline in the use of groundwater in the High Plains--withdrawals in the southern High Plains have already declined 11 percent since 1964. Growers are also taking other approaches, such as installing more efficient irrigation hardware and shifting to crops and varieties that require less water.

Central Valley California—The Central Valley of California is the most heavily pumped contiguous area in the United States. The watershed encompasses 20,000 square miles. Prior to development, the total groundwater circulation through the aquifer system was 650 billion gallons per year. From 1961 to 1978, about 7.2 trillion gallons per year were used for irrigation in the Central Valley--about half from groundwater. During this period, groundwater recharge was about 90 percent of withdrawals, but 82 percent of the recharge water came from irrigation water percolating back to the aquifers. Consequently, 261 billion gallons per year were withdrawn from groundwater storage. About half this amount drew down the water table and about half came from dewatering sediments that then compacted, leading to surface subsidence.

Since 1978, generally wet conditions in the Central Valley have stimulated recharge to the point where groundwater withdrawals from storage have ceased; some additions to storage have occurred. Given the wet weather and the current equilibrium in groundwater withdrawals and recharge, Central Valley water managers also believe that subsidence can be controlled. The key appears to be limiting withdrawals to keep the water level above its historical low point in subsidence-prone areas.

Southeastern and Atlantic Coastal Plain—Two regional aquifers provide water over a wide area along the Atlantic Coast. One covers Florida, southern and eastern Georgia, and adjacent areas of South Carolina and Alabama. The second runs along the Atlantic Coast between South Carolina and Long Island. Both have been extensively developed for agricultural, industrial, and municipal supplies. The former aquifer exists primarily in limestone and dolomite rock formations, the latter in unconsolidated sands and gravels of the coastal plain. In both, recharge is excellent due to humid climate and plentiful precipitation.

Extensive development in both aquifers has led to declines in water levels. In both aquifers, the effective lower boundary is the transition from circulating freshwater to underlying saline water which moves much slower, if at all. The location of the transition layer is deepest where recharge is greatest, rising toward the coastlines in the general direction of streamflow. In some parts of coastal Florida, and especially the area south of Lake Okeechobee, brackish or saline water extends to the top of the aquifer. Here especially, but also along the Atlantic Coast, development of the groundwater resource is encouraging saltwater intrusion.

In addition to saltwater intrusion, heavy pumping in these coastal plain aquifers also results in a reduction in instream flows. Both the limestone formations beneath the Southeastern Coastal Plain and the unconsolidated sands and gravels beneath the Atlantic Coastal Plain have many intersections with streambeds. Part of the reason that recharge is excellent for these aquifers is due to the ease with which streamflow can be diverted into the rock, sands, and gravels. Because heavy pumping induces a recharge response from all points on the compass, intensive development of these coastal aquifers both draws saline water from the oceans as well as drains freshwater from streams. While current pumping levels do not appear to be reducing aquifer storage from a volume perspective, some of the recharge water is saline and some of the flows

of coastal streams is being diminished. The long-term consequences of both situations are unfavorable.

Arizona Lowlands--The semiarid lowlands of Arizona cover 50,000 square miles and are the most heavily pumped region in the state. Irrigation is the largest use of water--two-thirds of it coming from groundwater. In recent years, competition has been growing between irrigators and municipalities. Tucson is entirely dependent upon groundwater and more than half of Phoenix's supply also comes from groundwater.

Vast quantities of groundwater are stored in sediments beneath the basin. Because potential evapotranspiration greatly exceeds precipitation, only limited amounts of water are available for natural recharge to the groundwater. Thus, extensive withdrawals of groundwater from storage have resulted. In 1981, about 1.7 trillion gallons of groundwater were pumped, of which 1.4 trillion gallons were used for irrigation. The current annual depletion of groundwater in the area is estimated at 650 billion gallons, or roughly 40 percent of withdrawals.

A number of hydrologic changes have resulted from intensive withdrawals of this magnitude. Groundwater levels have declined as much as 400 feet in some places since the 1940s and rates of water-level decline have been as great as 8 feet per year. In many areas, water-level declines have altered natural flow patterns that existed prior to development, creating a series of small, self-contained individual flow systems near each pumping center. In some areas of extensive water-level decline, the land surface has subsided as much as 12 feet and earth fissures have caused damage to public and private property. Concerns over land subsidence together with the self-limiting factors inherent in groundwater storage depletion--declining well yields and rising energy costs for pumping--are already acting to reduce the rate of withdrawals.

Groundwater Summary--Patterns of water development in the Nation have varied between two general conditions. In water deficient areas, such as southern Arizona and the southern High Plains, long-term withdrawal of groundwater from storage (groundwater mining) has supplied agricultural and municipal needs for many decades. These withdrawals cannot be sustained indefinitely. Decreases in withdrawals are already taking place as falling water levels cause well yields to decrease and pumping costs rise. On the other hand, in humid areas such as the Southeastern and Atlantic Coastal Plains, groundwater development has redistributed the natural flow pattern so that water which originally discharged to streams, to the sea, or to evapotranspiration is now diverted to well fields. In these areas, the groundwater system conveys water from source areas to points of use, and provides short-term storage during drought. The net depletion of groundwater in storage has been small since the aquifers were first developed. In the Central Valley of California, groundwater development has followed a course somewhat between these two conditions. Substantial withdrawals have occurred in the past, but the system appears to be in equilibrium between withdrawals and recharge at present. Coordinating the use of both surface and groundwater withdrawals, in which short-term depletions of groundwater are used to make up deficiencies in surface supplies during droughts, and recharging the aquifers when surface supplied become more plentiful, should be possible on a sustained basis in the future.

Instream Use

Instream uses include fish and wildlife propagation, recreational activities, maintenance of estuary salinity balances, hydropower generation, navigation, and waste dilution and transportation. In the past, waste dilution and transport was considered the primary use of instream flows. For example, Wollman and Bonem (1971) ignored the water flows needed for navigation and fish habitat, assuming that if sufficient water was available for waste dilution, those needs would also be met. They calculated the flows needed for waste dilution at different wastewater treatment rates. They concluded that if municipalities removed 70 percent of the waste delivered to them and private treatment facilities (generally industrial plants) removed 50 percent of the waste delivered to them, then the instream flows needed to preserve instream water quality would vary from 1423 bgd in 1985 to 5569 bgd in 2020. Assuming 90 percent treatment by both public and private facilities reduced the instream flow needs to 231 and 740 bgd in 1985 and 2020 respectively. The maximum volume of instream flows reported by Wollman and Bonem was 956 bgd. Thus, it was clear that with the assumption of 70 percent and 50 percent treatment levels, instream water quality would seriously deteriorate. THese findings served as a major impetus for passage of Public Law 92-500, the Federal Water Pollution Control Act Amendments of 1972, also known as the Clean Water Act. This law revised national policy toward instream water quality and wastewater treatment by limiting the use of instream flows for additional waste dilution and setting goals for attaining "fishable-swimmable" water quality in most streams through use of "best practicable" and "best attainable" wastewater treatment technologies.

Types of Uses--Instream flows for hydropower electricity generation are typically provided by dams. Instream flows typically do not have the required "head" to generate power without some sort of storage and/or diversion structure. Consequently, these will be reviewed in the surface water development section, below.

Freshwater stream flows are essential to keep the proper salinity balance in estuaries. Estuaries are often very fertile interfaces between saline waters from the oceans and freshwater from streams. The resulting brackish waters support extensive commercial and sport fisheries. For example, along the Gulf Coast, brackish water serves as vital breeding habitat for brown and white shrimp, blue crabs, redfish, and speckled trout. Even black bass will come down freshwater streams to feed on grass shrimp produced in the brackish water. Thus, maintaining the proper salinity balance with instream freshwater flows becomes critical to sustaining the fisheries. Too much freshwater, such as during floods, or too little freshwater during droughts are both equally harmful to fisheries depending on brackish water.

Instream flows are also essential for maintaining wetlands and swamps. These ecosystems are also the source of wildlife and fish habitat. They will be discussed further in a separate section, below.

Navigation and recreation activities, such as water skiing and swimming, generally do not suffer benefit losses over a long-term if low instream flows

occur. Wildlife and fish populations, on the other hand, do suffer long-term effects from low flows--effects from which they may take years to recover. Recreational and commercial activities associated with wildlife and fish will also suffer long-term losses in benefits if low flows destroy habitat or breeding populations. Consequently, this Assessment defines necessary instream flow levels based upon wildlife and fish needs.

Generalized Water Budgets--Generalized water budgets have been used by resource planners and managers to evaluate water resource allocations (Geological Survey 1984, Foxworthy and Moody 1986, and Flickinger 1987). Updated water budgets for water resource regions have been developed for this Assessment that reflect the latest information (preliminary water use data for 1985 from the U.S. Geological Survey). The first portion of the water budget is presented here, with the final part in Chapter 3, where water supply projections are developed. The objective of the first portion of the budget is to account for groundwater depletion rates and instream flows necessary for optimum wildlife and fish habitat. The balance of the instream flows are then available for consumption by off-stream uses.

Average annual stream outflows at the downstream end of major water resource regions have been estimated by Graczyk and others (1986), table 1.2. When the annual depletion of groundwater storage (from Foxworthy and Moody 1986) is deducted, the balance is the average annual net streamflow available for instream and offstream withdrawal uses. Net reservoir evaporation was estimated by Foxworthy and Moody (1986). The instream flows necessary for optimal fish and wildlife habitat were defined by Flickinger (1987). The amount of water available for offstream uses is the net amount remaining after instream flow requirements and net reservoir evaporation are deducted from average annual net streamflow. Put another way, the remainder is the limit on volume of surface water available for consumption in each water resource region. The analysis shows that instream flows in the Rio Grande, Upper Colorado and Lower Colorado water resource regions are insufficient to meet current needs for wildlife and fish habitat, much less allow any offstream use.

There are two implications of this current resource situation. The first is that groundwater withdrawals are essential in these regions for consumptive uses. The second is that if offstream uses exceed the net amount shown or even occur in the Rio Grande, Upper or Lower Colorado regions, then either groundwater mining is occurring in excess of the depletion estimates or fish and wildlife habitat is sub-optimal and other instream uses may be curtailed at certain times of the year. For example, navigation may prove impossible at certain times. In addition to providing habitat, in-stream flows are also essential for maintaining wetlands and swamp ecosystems and for maintaining salinity balances in brackish water ecosystems.

Surface Water Development[6]

The Nation's national endowment of surface water is, in total, more than adequate to meet current needs. The real issue is that the water is not always available when and where needed. Besides groundwater depletion, the other main reason for water scarcity in an area is increasing competition for what is essentially a fixed supply. For example, from 1960 to 1985, total withdrawals

Table 1.2--Average annual net streamflow, by water resources region

Water resources region	Area	Average annual stream outflows	Annual depletion of ground-water storage	Average annual net streamflow	Instream flow requirement[1]	Net reservoir evaporation	Net flow available for off-stream uses
	(1000 $miles^2$)	billion gallons per day					
New England	69	76.7	0.0	76.7	69	0.2	7.5
Mid-Atlantic	103	94.6	0.0	94.6	68.8	0.2	24.6
South Atlantic-Gulf	271	207	0.0	207	188.7	0.5	17.5
Great Lakes	134	75.2	0.0	75.2	64.0	0.3	10.9
Ohio[2]	160	138	0.0	138	122	0.4	15.6
Tennessee	43	42.9	0.0	42.9	38.5	0.0	4.4
Upper Mississippi[3]	181	77.6	0.0	77.6	69.7	0.6	7.3
Lower Mississippi[4]	106	433	5.8	427	359	6.0	62.0
Souris-Red-Rainy	55	7.2	0.0	7.2	3.7	0.4	3.1
Missouri	511	50.2	2.2	48.0	34.0	3.3	11.7
Arkansas-White-Red	244	56.3	3.6	52.7	46.2	1.4	5.1
Texas-Gulf	178	30.7	3.1	27.6	22.9	1.8	2.9
Rio Grande	137	1.8	0.0	1.8	2.3	0.8	-1.3[5]
Upper Colorado	103	8.3	0.0	8.3	8.0	1.7	-1.4[5]
Lower Colorado	155	2.5	2.1	0.4	6.9	3.6	-10.1[5]
Great Basin	139	4.2	0.0	4.2	3.4	0.2	0.6
Pacific Northwest	271	278	0.0	278	214	0.6	63.4
California	165	62.8	1.4	61.4	32.6	0.5	28.3
Alaska[6]	586	921	0.0	921	---	0.0	---
Hawaii[6]	6	13.6	0.0	13.6	---	0.0	---
Caribbean[6]	4	4.8	0.0	4.8	---	0.0	---

1 Instream flow requirements were taken from Flickinger (1987). They represent the optimal flows for fish and wildlife habitat--the most critical of instream uses--in average flow years.
2 Excluding outflows from the Tennessee region.
3 Excluding outflows from the Missouri region.
4 Land area for the Lower Mississippi region alone. Flows include inflows from the entire Mississippi River basin, including the Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red regions.
5 Negative numbers indicate that insufficient water currently exists to maintain optimal instream flow conditions and also avoid groundwater depletions.
6 No information on instream flow requirements was available for Alaska, Hawaii, and the Caribbean in Flickinger (1987).

from surface water increased 55 percent while population has only increased 32 percent. This means that surface withdrawals per capita have risen from 937 gallons to 1086 gallons--an increase of 16 percent.

Water use is analyzed from two perspectives--withdrawals and consumption. Withdrawals are water withdrawn or diverted from a source for use. Consumption is water no longer available for use because it has been evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed form the water environment. Some of the water withdrawn from a stream is consumed, and some is returned to the stream--usually after treatment. The water returned is then available for withdrawal and consumption downstream.

Surface water development issues in a particular reach of stream are often most concerned with withdrawals. But from a regional perspective, consumption is the more important measure of use. It is not unusual for withdrawals in a basin to be a multiple of the volume of runoff because much of the water withdrawn is returned to streams following waste treatment. But total annual consumption cannot exceed total annual runoff at the foot of the basin unless water is withdrawn from groundwater or surface storage. Consequently, water budgets focus on consumption, while surface water structures, such as dams, pipes, and canals, focus on withdrawals.

In 1985, total freshwater withdrawals in the United States was 343 bgd--83 billion from groundwater, 260 billion from surface water, and 0.6 billion from wastewater. Consumption in 1985 totaled 94 bgd--27 percent of withdrawals. Irrigation is the use that has the highest ratio of consumption to withdrawals, 51 percent (73.8 bgd consumed of 142.5 bgd withdrawn). Thermoelectric steam cooling is the use with the lowest ratio, 3 percent (4.8 bgd consumed of 130.9 bgd withdrawn). These are the two uses with the largest withdrawals. Domestic self-supplied and livestock watering have consumption ratios approaching the ratio of irrigation--47 and 45 percent respectively, but their combined withdrawals in 1985 only totaled 8.3 bgd. Municipal and industrial self-supplied use fall in the middle, with consumption ratios of 16 and 22 percent, respectively, on withdrawals of 36.7 and 24.5 bgd, respectively. Further information on withdrawal and consumption trends is presented in Chapter 2.

The annual consumption rate of 93 bgd directly comparable with the "Net flow available for offstream uses" column in table 1.2. Because irrigation consumes 10 times the water consumed by any other use and more than 3 times the total consumed by all other uses, obtaining more water for irrigation has been the prime water development problem in the U.S. earlier this century. But in recent years, increasing population and the development of diversified commercial and industrial economies in water resource regions where irrigation has historically been the dominant water use have increased the competition for water. The emergence of competing uses for water, both in the short-term during droughts and in the long-term to stimulate development, has heightened concern over the adequacy of water supplies and likelihood of water scarcities that hinder growth of both agricultural and non-agricultural economies.

Four approaches have been used to resolve problems of surface water availability: (1) developing structures to store water when it is plentiful and

convey it to the area where and when needed; (2) reducing or preventing certain water losses or uses deemed not beneficial; (3) attempts to increase the amount of precipitation; and (4) changing the nature and efficiency of water uses and treatment processes so water of lower quality can be used. Only the second approach deals with altering demand, the other three all seek to modify the timing or amount of the available supply.

Structural Surface Water Developments—Of the four approaches available for dealing with surface water scarcity, society has invested the most in building storage and conveyance structures. The unregulated flow of many of the Nation's rivers is highly variable throughout the year. For example, the rate of flow during floods is many times greater than during droughts. Some streams are called "ephemeral" because they cease flowing altogether during parts of the year. Most withdrawals, on the other hand, show much less variability--many being nearly constant on a weekly, and even a daily, basis. So even when the rate of withdrawals is small compared to the average annual flow rate of a river, there are many days during the year when even the desired amount of water is unavailable. Thus, reliance upon surface water as a source of supply usually requires a dam, creating a reservoir to store water from wet periods for use during dry periods. If the reservoir is located upstream from where the water is to be used, the water stored behind the dam may be released during dry periods to flow downstream to the point of use. In some cases, the stored water is withdrawn directly from the reservoir and carried by pipe or canals to the point of use. In either situation, there are usually minimum instream flows that must be maintained below the dam or the point where the water is diverted.

At present, there are 2,654 reservoirs and controlled natural lakes with capacities of 5,000 acre-feet or more in the United States and Puerto Rico. These have a combined normal storage capacity of 480 million acre-feet. The 574 largest reservoirs account for almost 90 percent of the total storage. In addition, there are at least 50,000 smaller reservoirs with capacities in the range of 50 to 5,000 acre-feet and about 2 million smaller farm ponds used for storage, table 1.3 (U.S. Army Corps of Engineers, 1981). The distribution of reservoir capacity in the water resource regions of the Nation, expressed as the sum of the normal capacities of all reservoirs larger than 5,000 acre-feet is shown in table 1.4 (U.S. Army Corps of Engineers 1981). Normal capacity--the capacity exceeded only during floods--represents a desired storage level for the reservoir that is, on average, about two-thirds of maximum capacity.

Reservoirs are often described as having a "safe yield," which is the amount of water that can be withdrawn or released on an ongoing basis with an acceptable risk of a supply interruption. If the desired safe yield is small in comparison to the average flow rate of the river (say 10 percent of average flow), then the dry period for which the reservoir stores water may be a few weeks or months of the driest part of the year. For a safe yield approaching the average annual flow of the river (between 50 and 90 percent of average flow), the dry period for which the reservoir stores water may span several years. The required size of a reservoir to satisfy a given demand is determined by the volume of water necessary to carry users through the dry period. This volume is the product of the flow deficiency (demand minus flow) and the duration of the dry period.

Table 1.3--Summary of reservoir storage capacity, including controlled natural lakes, in the United States and Puerto Rico

Reservoir size[1]	Number of reservoirs	Total reservoir storage	
		Total capacity	Percent of total
---acre feet---	--number--	---acre feet--	----percent-----
Greater than 10,000,000	5	107,655,000	22.4
100,000 to 10,000,000	569	322,852,000	67.3
50,000 to 100,000	295	20,557,000	4.3
25,000 to 50,000	374	13,092,000	2.7
5,000 to 25,000	1411	15,632,000	3.3
Total[2]	2654	479,788,000	100.0

[1] Reservoir size is expressed as normal capacity of storage, which is the total storage space in a reservoir below the normal water retention level. Normal capacity includes dead storage and inactive storage but excludes any flood-control or surcharge storage.
[2] In addition, there are perhaps at least 50,000 reservoirs with capacities ranging from 50 to 5,000 acre-feet, and about 2 million smaller farm ponds used for storage.

Source: Anon. (1984), who cited U.S. Army Corps of Engineers (1981)

As is the case with pumping groundwater, the law of diminishing returns applies. Each successive increment in safe yield requires more storage than the preceding increment. For example, doubling the safe yield would require more than doubling the storage capacity, which, in turn, requires more than doubling the construction costs. Hardison (1972) found that, for all the water resource regions in the continental U.S., the point at which safe yield reaches its maximum is when storage is in the range of 160 to 460 percent of the average renewable supply of the region. The variation depends, in part, upon the use or variety of uses (such as water supply, flood control, power generation) served by the stored water.

Another index of reservoir capacity in a region is the normal reservoir capacity in the region per unit area of the region. Even if Alaska and Hawaii are excluded, the range in intensity of development among regions is considerable--ranging from 24 acre-feet per square mile in the Great Basin to 366 acre-feet per square mile in the Upper Colorado. Factors influencing the intensity of development include the availability of precipitation and groundwater to help satisfy water demands, the magnitude of the surface flows available for development, the existence of suitable reservoir sites, and political and institutional factors governing reservoir development. The upper limits on development of suitable sites among the regions appear to range from about 250 to about 500 acre-feet per square mile (Langbein 1982).

Table 1.4--Distribution of reservoir storage by water resource region

Water resource region	Area in region	Average renewable supply	Normal reservoir capacity		
			Million acre-ft	Acre-ft per square mile	Percentage of renew. supply
	-1000 mi^2-	---bgd---			
New England	69	77.3	13.0	188	15.0
Mid-Atlantic	103	96.5	10.3	100	9.5
South Atlantic-Gulf	271	213.0	38.7	143	16.0
Great Lakes	134	76.8	6.9	51	7.9
Ohio[1]	160	140.0	19.6	123	12.0
Tennessee	43	43.3	11.2	260	23.0
Upper Mississippi[2]	181	79.7	12.2	67	14.0
Lower Mississippi[3]	160	76.0	5.7	36	6.7
Souris-Red-Rainy	55	7.7	8.0	145	93.0
Missouri	511	67.3	84.3	165	112.0
Arkansas-White-Red	244	63.7	31.8	130	45.0
Texas-Gulf	178	35.9	24.7	139	61.0
Rio Grande	137	5.0	10.4	76	189.0
Upper Colorado	103	12.3	37.7	366	261.0
Lower Colorado[4]	155	-1.1[5]	32.7	211	299.0
Great Basin	139	8.3	3.3	24	35.0
Pacific Northwest	271	291.0	60.9	225	19.0
California	165	86.9	38.8	235	42.0
Alaska	586	921.0	1.5	3	0.1
Hawaii	6	14.3	0.0	2	0.0
Caribbean	4	5.1	0.3	90	5.2

[1] Exclusive of outflows from the Tennessee water resource region
[2] Exclusive of outflows from the Missouri water resource region
[3] Exclusive of outflows from the Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red water resource regions.
[4] Represents conditions in the Upper and Lower Colorado water resource regions.
[5] The annual renewable supply of the combined Upper and Lower Colorado water resource regions is 11.2 bgd. The supply for the Upper Colorado was reported as 12.3; a separate supply estimate was not reported for the Lower Colorado.

Source: Anon. (1984) and U.S. Army Corps of Engineers (1981)

Langbein (1982) presented a concise summary of the historical trends in reservoir development. In summary, the growth rate in capacity of major reservoirs in the United States averaged about 80 percent per decade from 1920 to the early 1960s. Since then, reservoir capacity has increased at a much slower rate. The current status of reservoir development is about 450 million acre-feet in place. Based on a number of intensive surveys, there remain about 750 million acre-feet of potential storage in the continental U.S. where building dams is feasible from an engineering perspective. But because most of the cost-effective sites have already been developed, adding a significant

portion of the potential storage to the current level of development will entail very high investments--so high as to be nearly prohibitive. If so, the Nation's current reservoir capacity may be near the limit of development.

There are, however, other means for coping with providing water to meet future needs. Most of these means are called "non-structural" measures that require changing management guidelines or regulations. Such changes, of course, often have costs of their own--social and environmental as well as economic. For example, there are a large number of multiple-purpose reservoirs where withdrawals are not now the primary purpose of the reservoirs' management. A shift in the allocation of water could make additional capacity available to meet future water supply shortages in time of drought. Better management has the potential for increasing safe yields, up to a limit, without increasing storage (Toebes 1981). An example of better reservoir management is found in the Washington, DC metropolitan area (Sheer 1983). The area's water supply comes from three rivers and four reservoirs: the Potomac, with one reservoir 200 miles upstream; the Patuxent in Maryland, with Tridelphia and Rocky Gorge Reservoirs; and the Occoquan, with Occoquan Reservoir. The sum of the safe yields of these three sources is 513 million gallons per day, but requirements for water are expected to reach 750 million gallons per day by the year 2000. Through analyses of the complete system--intentionally ignoring certain of the institutional constraints of three separate water supply agencies--it was found that the existing structures could reliably supply water until the year 2030. After recognizing the large gains that could be achieved through flexible and integrated operations, the parties involved forged the necessary legal and financial agreements to make this possible. The savings are in excess of $200 million. These savings were achieved through systems analysis techniques, such as linear programming, synthetic hydrology, statistical analysis, hydrologic modeling, long-range probabilistic forecasting, and computer simulation.

The trend towards using nonstructural measures to solve problems instead of building more dams places greater dependence upon management skill, understanding the nature of river behavior, and better river forecasting. At some point in the future, the potentials for conservation and better management may become less cost effective than building additional storage.

<u>Controlling Losses and Low-Priority Uses</u>--A number of options are available for eliminating or curtailing water losses and uses judged not beneficial, given current supplies. One is to reduce water leaks from pipes and ditches delivering water to municipal and irrigation users. Stopping leaks does not make more water available in a region, because the leakage returns to aquifers. But it is a way of increasing the usable supply at low cost because the leakage water has been diverted, treated and transported--often at high cost--yet is never available for use. Moyer and others (1983) and Pilzer (1981) have analyzed leak detection programs.

Implementing voluntary or mandatory rationing schemes is the quickest way to curtail low priority water uses. Mandatory actions such as restricting lawn watering to one day in three or prohibiting the washing of automobiles during a drought period have been employed during recent droughts in the East. Some citizens have adapted to such restrictions by using rinse water from laundry to water vegetable gardens or wash vehicles--a form of household recycling. Other

forms of voluntary household conservation include installing a showerhead that emits fewer gallons per minute and bending the float arm in toilet tanks to reduce the volume of water per flush.

Voluntary or mandatory rationing schemes are but one type of institutional modification that can be made to reduce demand and stretch available supplies. Experience with such institutional changes demonstrates that there are few absolute water requirements. Most offstream water users have considerable flexibility in selecting their rates of water intake and recycling. Water use may change, for example, in response to changes in water prices or waste treatment charges (Foster and Beattie, 1979, Strudler and Strand, 1983, and Young and others, 1983). Installation of water meters has led to reductions in use in use of water in some areas; a contributing factor is often the switch from flat rate to variable rate structures. Industrial users may change water use practices in response to energy prices and waste treatment regulations (Babin and others, 1980). Irrigators are moving to more efficient irrigation hardware and management methods. The Federal Interagency Task Force on Irrigation Efficiencies (1979) estimated that $5 billion in public and private expenditures on water conservation by 2010 could reduce withdrawals by 13 to 18 bgd and thereby make 1.7 to 4.5 billion gallons available for new consumptive uses. In some western states, the appropriation doctrine of water rights limits the flexibility of users to sell water not currently needed--often placing users in a "use it or lose it" situation. Modifications in the water rights institution can help to shift water from users who have more senior rights to those with junior rights either temporarily, so the owner of senior rights does not lose them permanently, or through markets so more junior users can bid for the rights.

A detailed discussion of the many forces influencing water use and of various demand management practices and policies is beyond the scope of this Assessment. Kelso and others (1973) examined some of these problems in a case study of Arizona. Hirshleifer and others (1969) and Baumol and Oates (1979) provide a more general discussion of these topics.

Increasing Precipitation--Weather modification is another approach to enhancing water supplies. Serious scientific attention to techniques for artificially increasing precipitation began around 1946. There have been more than a dozen major research projects dealing with this subject in the United States. Findings in these studies are still the subject of controversy in the scientific literature. See, for example, Hess (1974), Tukey and others (1978) and Braham (1979).

Ski areas in California and Colorado are already practicing weather modification on a commercial basis. But serious impacts on stream channels can occur where snow accumulates in excess of what stream channels can handle during snowmelt. Reservoir storage must be available to store the increased snowmelt if it is to contribute to increasing water supplies in a region.

Using Low Quality Water--Using water of lower quality, and in particular, recycling treated wastewater, has not become as popular as some forecast when Congress was debating the Federal Water Pollution Control Act Amendments of 1972. Wastewater use today is 5 percent lower than it was in 1960. But

between then and now, use peaked 10 percent higher than present and dropped 20 percent below present. So a decided trend in wastewater use is not evident--save that it has not increased nearly as much as expected. Wastewater reuse is not new. Bethlehem Steel in Baltimore, MD has been using over 100 million gallons per day of Baltimore's treated wastewater since 1942. The use of saline water has increased seven-fold from 1950 to 1980 (Solley and others, 1983), mostly for industrial cooling purposes. The use of saline water represents an enhancement of supply. Using saline water presents problems for industry, but the rate of increase in use demonstrates that solving those problems has proven less costly than acquiring additional supplies of freshwater.

Quality of Water Available for Use[7]

Water-quality degradation has been widely publicized, but has not become a major limitation on water availability or use nationwide. A relative abundance of good quality surface water still exists, even though serious water-quality problems have developed in some stream reaches and some streams cannot support the full range of desired uses.

There are six major categories of pollutants:

- -- <u>Fecal coliform bacteria</u>: Used as indicators of the presence of other disease causing organisms.
- -- <u>Nutrients</u>: Stimulate the growth of aquatic plants; can result in altered aquatic communities, fish kills, excess weed growth, unpleasant odors and tastes, and impaired recreational uses.
- -- <u>Silts and suspended solids</u>: Modify aquatic community through habitat alteration. Impair fish respiration and reproduction. Reduce plant productivity by reducing sunlight penetration and thereby photosynthesis. Aesthetic impacts reduce recreational uses. Also known as turbidity.
- -- <u>Biochemical oxygen demand (BOD)</u>: Reflects materials that reduce the availability of dissolved oxygen, which is crucial to respiration of fish and aquatic invertebrates.
- -- <u>Salinity and total dissolved solids</u>: Impair the use of water for drinking and crop irrigation and adversely affect aquatic ecosystems
- -- <u>Toxics</u>: Can cause death, mutation, or reproductive failure in fish and wildlife and may pose carcinogenic or other health threats to humans.

Water pollution is usually attributed to one of two sources--**point** or **nonpoint**--depending upon how the water enters the aquatic environment. Point sources discharge a flow to the aquatic environment through a pipe, ditch, or other mode of conveyance. Nonpoint-sources discharge a flow to the aquatic environment as runoff, unconcentrated by a conveyance structure. After introducing the current water quality situation in general terms, specific discussions of point and nonpoint source pollution follow.

During the 1960s, the growing environmental awareness of water quality issues led to passage of several laws pertaining to water quality. The Clean Water Act of 1972 (amended in 1977 and 1981) and the Safe Drinking Water Act of 1974 (Public Law 93-523) were two of the most prominent. These laws have motivated both the public and private sectors to spend billions of dollars on different types of pollution abatement programs, designed mainly to reduce point-source

pollution and improve instream quality. For example, more than $100 billion was spent for pollution control between 1974 and 1981 (U.S. Environmental Protection Agency 1984). From 1972 to 1982, total biochemical oxygen demand (BOD) load from municipal waste treatment plants decreased an estimated 46 percent and industrial load decreased at least 71 percent (Association of State and Interstate Water Pollution Control Administrators, 1984). These gains in waste treatment occurred simultaneously with increases in population and real Gross National Product (GNP) of 10 percent and 27 percent respectively.

Significant improvements have been reported by the National Stream Quality Accounting Network (NASQUAN) stations operated by USGS and the National Stream Quality Surveillance System (NWQSS) operated by EPA. Between October 1974 and October 1984, widespread decreases in fecal coliform bacteria and lead concentrations, and to a lesser extent, phosphorus concentrations have been monitored downstream of major point-source dischargers (Smith and others, 1986 and 1987). These trends provide some evidence of the benefits of improved wastewater treatment for point-source discharges and benefits from the switch to unleaded gasoline. The same studies, though, have also shown widespread increases in nitrate, chloride, arsenic, and cadmium concentrations. Recorded increases in nitrogen fertilizer applications and use of salt on highways along with regionally variable trends in coal production and combustion are reflected in increasing nonpoint-source pollution loads.

Every two years, EPA summarizes water-quality reports submitted by the States and other jurisdictions in accordance with Section 305(b) of the Clean Water Act, as amended. The 1986 Report (Environmental Protection Agency, 1987) marked the first time that all 56 States and jurisdictions submitted data.[8] The data show that three-fourths of the Nation's rivers, lakes, and streams are fully supporting the uses designated for those water bodies, table 1.5.

The States were asked to rank the sources of pollution impairing the ability of surface and groundwater to fulfill desired uses. Nonpoint-sources are responsible for impairing water quality much more frequently than point source pollution. Of assessed waters with impaired uses, nonpoint-sources of pollution were responsible in 76 percent of lake acres, 65 percent of stream miles, and 45 percent of estuarine square miles. Point sources were responsible in 34 percent of estuarine square miles, 27 percent of stream miles, and 9 percent of lake acres.

In their 1986 reports under Section 305(b) of the Clean Water Act, the states were asked to provide individual discussions of any issues they had found to be of either current or emerging special concern (Environmental Protection Agency 1987). The surface water concerns most often discussed by the States included mine drainage, nonpoint-source pollution, toxics and public health, acid deposition, groundwater protection, and wetlands loss.[9]

In the mid-1970s, experts believed that point-source pollution was the more significant source. Accordingly, efforts to improve water quality were focussed upon point sources discharging more than 5 million gallons per day. The effect was to target grant and enforcement programs on roughly a fifth of the dischargers, who in total, created nearly four-fifths of the total volume discharged. Obtaining compliance by this group required substantial public and

Table 1.5--Degree of designated use supported by the Nation's waters

	Rivers	Lakes	Estuaries[1]
	--miles--	--acres---	square miles
Total in U.S.	1,800,000	39,400,000	32,000
Total Assessed	370,544	12,531,846	17,606
(% of total in U.S.)	(21%)	(32%)	(55%)
Fully supporting uses	274,537	9,202,752	13,154
(% of total assessed)	(74%)	(73%)	(75%)
Uses are impaired			
Partially supporting uses	70,196	2,181,331	3,224
(% of total assessed)	(19%)	(17%)	(18%)
Not supporting uses	22,974	859,080	1,177
(% of total assessed)	(6%)	(7%)	(7%)
Unknown support of uses	2,127	288,684	51
(% of total assessed	(1%)	(2%)	(0.3%)

[1] Total U.S. estuarine square miles exclude Alaska

Source: Environmental Protection Agency (1987)

private investments and water quality has improved. But obtaining similar compliance by the remaining large number of small point dischargers will be more difficult and not nearly as cost-effective. Further, as the large point-source discharges were brought into compliance, it became more and more evident that nonpoint-sources--which are even more difficult to track and costly to control than small point sources--were also a major cause of water quality problems.

Point-Source Pollution

There are three major types of point-source dischargers--municipal sewage treatment plants, industrial facilities, and combined sewer overflows. Municipal sewage treatment plants commonly discharge BOD, bacteria, nutrients, ammonia, and toxics. Industrial facilities commonly discharge BOD. There are a wide variety of other substances discharged by industries, depending upon their manufacturing processes. Chief concerns center around toxics. Combined sewer overflows occur where urban stormwater runoff flows into catch basins that empty into the same sewer pipes as residential and industrial wasteflows. If the runoff volume exceeds the short-term conveyance capacity of the sewers,

the excess water causes sewers to overflow and dump a mixture of stormwater runoff and untreated residential and industrial waste into nearby surface waters. The most common pollutants in combined sewer overflows are BOD, bacteria, turbidity, total dissolved solids, ammonia, and toxics.

Biochemical Oxygen Demand--In the decade after passage of the Clean Water Act, municipal loads of BOD decreased 46 percent and industrial BOD loads decreased 71 percent nationally. Industrial sources currently contribute about one-third of the total point-source BOD load nationwide. Most of the reduction in the industrial BOD load occurred in the mid-1970s, shortly after the law was passed. Municipal reductions occurred later, in the early 1980s. Federal expenditures for upgrading municipal facilities under the Construction Grants Program reached a maximum in 1980 and totaled $35 billion from 1972 to 1982. Smith and others (1987) outlined results of statistical analyses of BOD reductions and changes in dissolved oxygen deficits. They reported little statistical support for concluding that construction expenditures reducing BOD loads had a significant effect on reducing dissolved oxygen deficits. This finding is contrary to surveys of state and local pollution control personnel (Association of State and Interstate Water Pollution Control Administrators 1984) which reported increased in-stream dissolved oxygen concentrations.

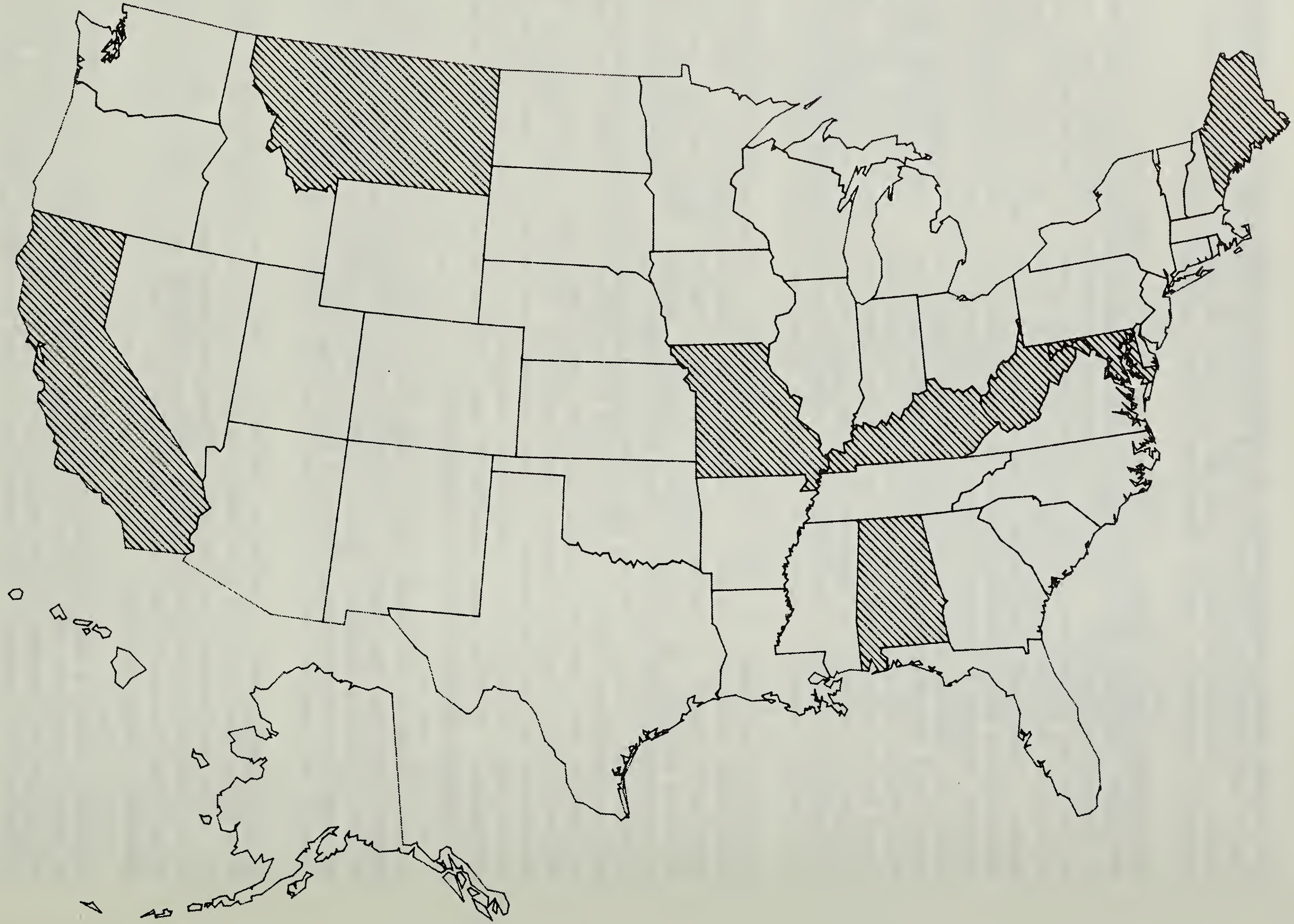
Bacteria--Decreases in fecal coliform and fecal streptococcal bacteria were widespread from 1972 to 1982. Decreases in fecal streptococcal bacteria were especially common in parts of the Gulf Coast, central Mississippi, and the Columbia basins. Decreases in both forms of bacteria were common in the Arkansas-White-Red basin and along the Atlantic Coast. A major emphasis of the Construction Grants Program has been installation of secondary treatment as the minimum treatment level. This has led to construction of centralized waste collection and treatment facilities for the first time in many communities. Whenever new collection sewers were installed, they were kept separate from stormwater collection sewers; in many cases, new residential and industrial sewers were constructed to segregate residential and industrial wastes from stormwater. Another major source of fecal bacteria is runoff from animal feedlots--a nonpoint-source of bacteria.

Several lines of evidence suggest that the widespread decreases in fecal bacteria are due to improved municipal waste treatment and not to any concerted effort to reduce feedlot runoff. Where fecal bacteria increases have been measured in recent years, they are positively associated with cattle population density and feedlot activity in the watershed (Smith and others 1987).

Mine Drainage--When thinking of industrial facilities, manufacturing plants more often come to mind than resource extraction facilities, such as mines. But water pollution from resource extraction operations was recognized as a major problem as farr back as the 1800s. Although most resource extraction operations create nonpoint-source pollution, mines create both point- and nonpoint-source pollution.

In spite of the tremendous strides that the mining industry has made to clean up abandoned mines and control discharges from active ones, mine drainage was still reported as one of the major point-source concerns by nine of the states in their 305(b) reports (Environmental Protection Agency 1987), figure 1.4.

Figure 1.4--States reporting mine drainage a special concern



In addition, mining activities were widely reported by states as a cause of use impairment across the Nation.

Impacts to rivers and lakes come from a variety of mine-related sources. Acid mine drainage occurs when sulfur-bearing minerals are exposed to water and air in the mining process, combining to form sulfuric acid. Contaminated water draining or seeping from mines can create acidic conditions in receiving streams; may dissolve metals from geologic formations and carry these into waterways; and when entering a pH-neutral stream, may form iron compounds that "settle out" and smother bottom-dwelling aquatic organisms, creating havoc with aquatic ecosystems (Environmental Protection Agency 1987). These factors can devastate streams for miles downstream of mining activity. Cleanup and control, always a complex issue, is complicated further because many of the worst problems come from mines that were operated and abandoned long before water quality impacts were a consideration.

In addition, metal mines, such as silver, lead, and copper mines most widely found in the western U.S., can directly contribute metal-laden runoff through tailings piles and mine seepage. Sedimentation, erosion, and habitat distruction, which can result from earthmoving activities, are also significant problems associated with mining.

Point-source discharges from active mines are regulated by EPA and state National Pollutant Discharge Elimination System permits. Many states also use Best Management Practices (BMPs) to regulate nonpoint emissions from mines. Pollution from abandoned mines is addressed in the Federal Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). Programs to control runoff from abandoned mines include treating wastes; reclaiming land through refilling, regrading, and replanting; and sealing mine openings.

Nonpoint-Source Pollution

There are seven major categories of nonpoint-source pollution--all dealing with one form of runoff or another. The categories and the types of pollutants commonly found are:

- -- Agricultural runoff: Nutrients, turbidity, total dissolved solids, toxics, and bacteria.
- -- Urban runoff: Same pollutant categories as agricultural runoff, but in different concentrations.
- -- Silvicultural runoff: Nutrients, turbidity, toxics.
- -- Construction runoff: Same pollutant categories as silvicultural runoff, but in different concentrations.
- -- Mining runoff: Turbidity, acids, toxics, total dissolved solids.
- -- Landfills/spills: Toxics, miscellaneous substances.
- -- Septic systems: Bacteria, nutrients.

Bacteria, nutrients (principally nitrates, ammonia, phosphorus), and turbidity (suspended sediments) are the key nonpoint-source pollutants.

Thomas (1985) suggested that nonpoint-source pollution may prevent achievement of national water-quality goals even after complete implementation of planned

point-source controls. Sixteen states identified nonpoint-source pollution as an issue of special concern in their 305(b) reports, figure 1.5. Suspended sediment and nutrients from agricultural sources are cited as the most damaging nonpoint-source pollutants nationally. The cost of the hydrologic impacts of soil erosion and related nutrients on aquatic ecosystems has been estimated at $3.5 billion annually (Clark and others 1985). In spite of wide recognition of the nonpoint-source pollution problem, little information is available on the long-term trends of nonpoint-source pollution.

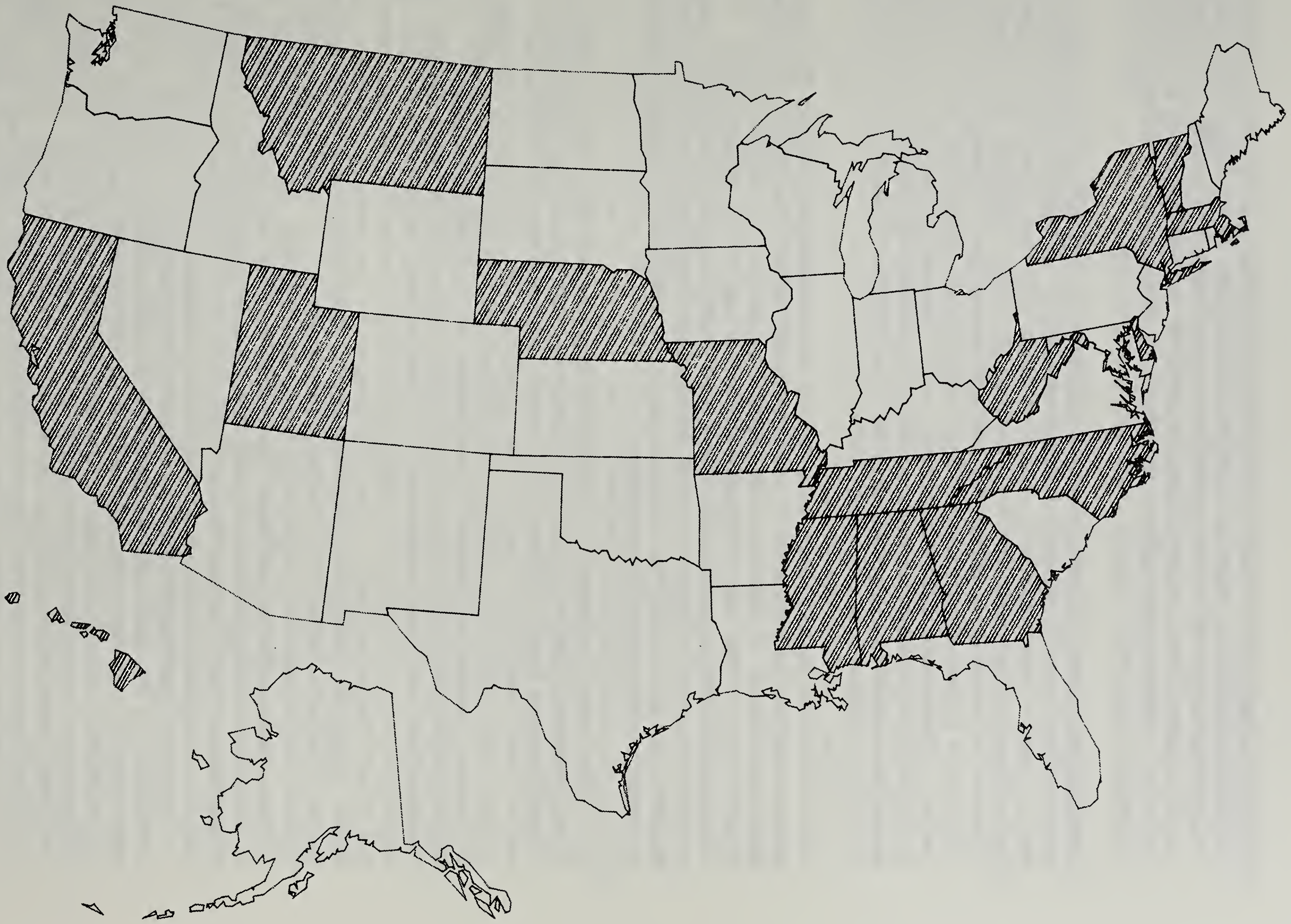
Farm activity increased significantly between 1972 and 1982. Fertilizer application rates increased 68 percent between 1970 and 1981 as farm production increased rapidly (Smith and others 1987). The extent to which these and other changes in land management practices, primarily agricultural, are reflected in trends in suspended solids, nitrogen, and phosphorus concentrations in streams has largely been a matter of guesswork because no systematic long-term studies are available (Smith and others 1987).

<u>Suspended Sediment</u>--Nationwide trends in suspended sediment concentrations were mixed--roughly half the changes were increases, the other half decreases. Increases in suspended sediment concentrations occurred in watersheds where the predominant forms of land use have historically been associated with high rates of soil erosion, such as logging in the Columbia basin. Smith and others (1987) tested the association between suspended sediment trends in streams and erosion rates for specific land use categories by using the U.S.D.A. National Resources Inventory from 1982. They found that trends in suspended sediments were not significantly associated with estimates of total watershed soils erosion. Increases in suspended sediments, however, were significantly related to the fraction of total soil erosion contributed by cropland in the watershed and to the absolute magnitude of cropland erosion in the watershed. In contrast to these results, suspended sediment concentrations were not associated with erosion rates on either forest land, pasture, or range.

Factors other than soil erosion have played an important part in suspended sediment concentrations in streams in some watersheds. For example, some streams in the Columbia basin carried increased sediment loads in 1980 and 1981 after the eruption of Mount St. Helens. Declining concentrations have been reported at several locations in the Missouri River basin. These have been clearly traced to the effects of reservoir construction throughout that basin in the 1950s and 1960s (Williams and Wolman 1986).

<u>Total Phosphorus</u>--Trends in total phosphorus concentrations followed a pattern similar to that of suspended sediments with the exception that decreases in total phosphorus were prevalent in the Great Lakes and Upper Mississippi basins. Decreases in the Great Lakes region resulted, in part, from point-source reductions in the late 1970s. Increases in the Great Lakes region resulted largely from nonpoint-sources. As with sediments, phosphorus increases are significantly associated with various measures of agricultural land use, including fertilized acreage and cattle population density. Additional evidence is provided by the close relationship between changes in phosphorus concentrations and changes in suspended sediment concentrations, which have already been shown closely linked to agricultural land use changes.

Figure 1.5--States reporting nonpoint-source pollution as a special concern



Total Nitrates—In contrast to suspended sediments and total phosphorus, increasing trends in total nitrate concentrations were common and widespread. Increasing trends were most prevalent in the North and South. Increases in total nitrates were strongly associated with several measures of agricultural activity, including fertilized acreage as a percentage of watershed areas, livestock population density, and feedlot activity.

In addition to agricultural runoff, atmospheric deposition has become a major source of nitrate in surface waters, especially in forested watersheds of the North. Few nitrate deposition records exist for the years before 1980, but those that do (National Academy of Sciences, 1983; Galloway and others, 1982), together with emission estimates for nitrous oxides (Gschwandtner and others, 1985) show a general pattern of increasing rates during the 1974-to-1981 period. Consistent with this trend, total nitrate increases at monitoring stations were strongly associated with high levels of atmospheric nitrate deposition, particularly in the Ohio, Mid-Atlantic, Great Lakes, and Upper Mississippi water resource regions.

Point-source nitrogen loads declined in many watersheds during the late 1970s as a result of improvements in municipal wastewater treatment facilities. But the improvements in point-source nitrate loads had no statistically significant effect upon nitrate concentrations instream (Smith and others 1987). Consequently, total nitrate trends appear more related to nonpoint sources than to point sources. In particular, atmospheric deposition of nitrates may have played a large role in the frequent occurrence of total nitrate increases in midwestern and eastern watersheds.

Given the large increases in fertilizer application rates that occurred in the 1970s and early 1980s, it is not surprising that trends in both total phosphorus and total nitrates show strong associations with measures of agricultural activity. Despite the importance of agricultural sources, however, distinct differences exist in the trend patterns for phosphorus and nitrates. Increasing trends in phosphorus and suspended sediment concentrations occurred with only moderate frequency and were largely confined to major mid-continent watersheds. In comparison, increasing trends in nitrate concentrations occurred with high frequency and were widely distributed from the Great Plains eastward. The differences in the patterns of these pollutants appear to be the result of three factors. First, atmospheric deposition seems to have played a large role in the high frequency of increasing trends in nitrate concentrations, especially among the forested watersheds in the Lake States, Central States and East—the North in this assessment. Second, the low frequency increasing trends in, and strong association between, phosphorus and suspended sediment concentrations suggests that anticipated increases in phosphorus concentrations resulting from increases in agricultural activity in the 1970s have been moderated or delayed by temporary storage of the phosphorus in the soil and sediments in stream channels. Ellis (1973) and Hook and others (1973) described mechanisms whereby phosphorus applied to forest and agricultural soils in wastewater was either adsorbed by soil colloids and sediments or precipitated from soil solution. Both of these mechanisms functioned most effectively in the top 6 to 12 inches of the soil. These findings support the moderation or delay findings of Smith and others (1987). Third, point-source control efforts during the late 1970s and early 1980s were

focussed much more heavily upon phosphorus than nitrates because phosphorus was considered more limiting to eutrophication in freshwater ecosystems. The results of this policy difference are observable both in the greater ratio of phosphorus decreasing trends to increasing trends and in the stronger association of phosphorus declining trends with point-source load concentrations.

Perhaps the greatest consequence of differences in the nitrogen and phosphorus concentration trend patters is seen in recent changes in the volumes of nutrients delivered to coastal freshwater and marine estuaries. Nitrate loads to Atlantic Coast estuaries, the Great Lakes, and the Gulf of Mexico increased between 25 and 45 percent between 1974 and 1981, while phosphorus concentrations have declined as much as 20 percent. The exception to this phosphorus finding is the South Atlantic Coast and Gulf Coast where increases in sediment deliveries have brought increases in phosphorus too. There is increasing concern over the problem of eutrophication in estuaries and debate has arisen over the need for nutrient controls in tributary basins (Thomas 1985). Increased deliveries of nitrate to estuaries are a major concern because of the tendency of nitrogen to be the limiting factor for eutrophication in many estuarine environments. For example, emerging problems due to excessive nutrients in the Chesapeake Bay resulted in the Governors of Maryland, Pennsylvania, and Virginia and the Mayor of the District of Columbia creating the Chesapeake Bay Agreement of 1983. Since signing the agreement, interagency networks have been developed to deliver educational, technical and financial assistance to discharges and landowners. Grants to install BMPs for control of nonpoint-source pollution have reduced runoff and erosion from 61,120 agricultural acres by 364,000 tons of sediment and provided controls for 830,000 tons of animal waste. U.S. Environmental Protection Agency (1987) has published additional case studies where reductions in nutrient and sediment deliveries to estuaries, lakes, and streams have recently been accomplished.

<u>Total Dissolved Solids (Salinity)</u>--Increasing trends in concentrations of chloride, sulfate, and sodium in streams have occurred since the mid-1970s. The magnitude of the increase--averaging 30 percent--and the wide distribution of these trends represents a significant increase in salinity in the Nation's waters.

Several factors appear responsible for the general pattern of salinity increases. First, chloride trends were moderately correlated with population changes during the study period. Because human wastes are a major source of chloride in many populated basins, the increasing trends are not unexpected. Second, salt use on highways increased nationally by a factor of 12 between 1950 and 1980. This trend stands out as a likely cause for sodium and chloride trends in watersheds where a significant portion of annual precipitation falls in the winter months. Increasing sodium and chloride concentrations were significantly associated with high rates of highway salt use and with large increases in salt use, especially in the Ohio, Tennessee, lower Missouri, and Arkansas-White-Red water resource regions. Although irrigated agriculture has a large influence on salinity in certain western rivers, chloride trends were not significantly correlated with changes in irrigated acreages nationally (Smith and others 1987). Finally, increases in sulfates were especially frequent in the Missouri, Arkansas-White-Red, and Tennessee water resource

regions and were highly correlated with changes in open-pit coal production. Sulfate trends were not significantly correlated with underground coal mining in the same water resource regions.

In contrast to much of the rest of the Nation, the Upper and Lower Colorado water resource regions showed significant decreases in salinity between 1974 and 1981. Decreases in chloride concentrations in these watersheds are noteworthy in view of the history of salt problems there. The decreases have recently been traced partly to salinity control efforts and partly to the temporary effects of reservoir filling in the early 1970s.

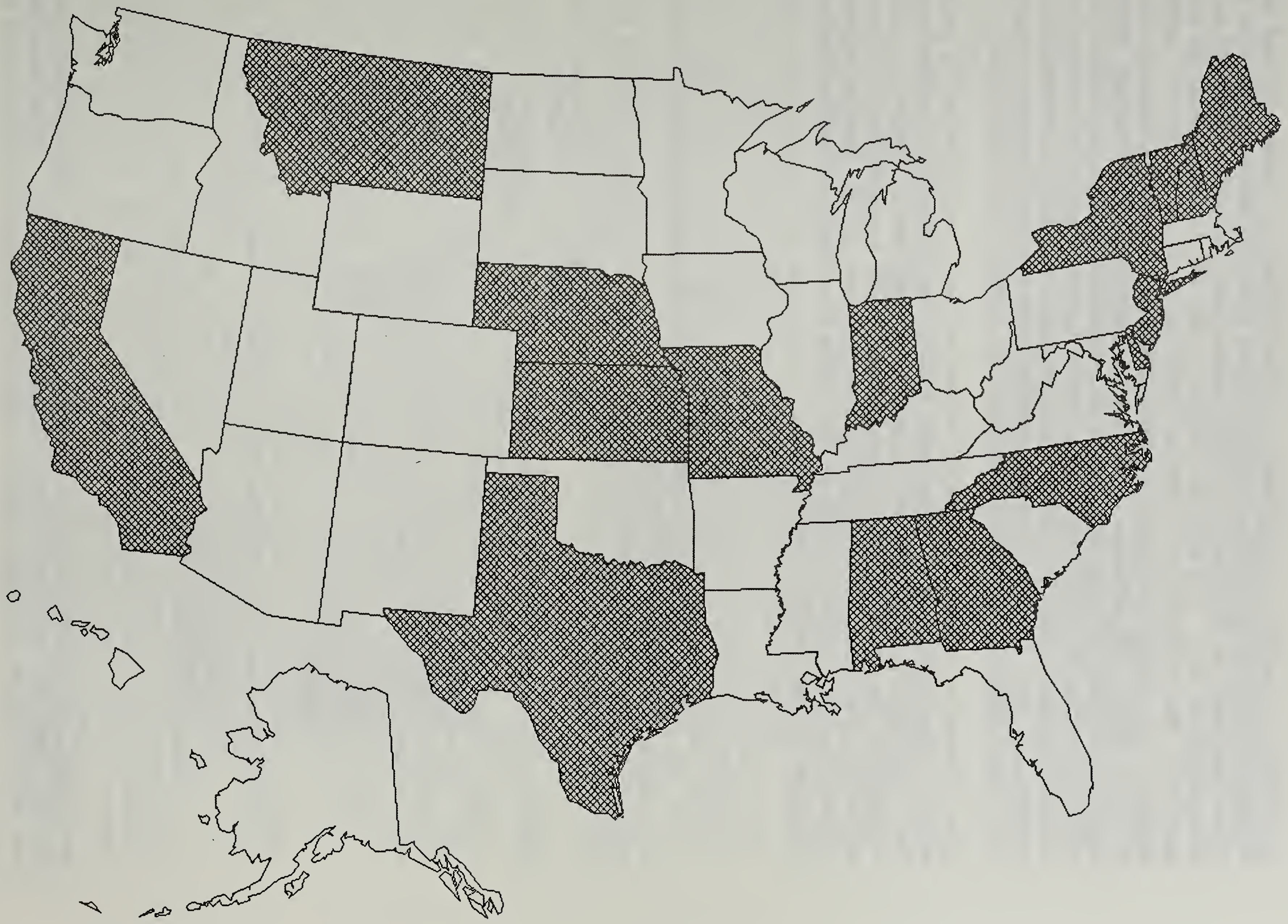
Toxics--Although many chemicals have toxic effects if present in sufficient amounts--e.g. table salt--a number of chemicals appear to have adverse and long-term effects at extremely low concentrations. These are commonly referred to as toxics. They may be either naturally occurring, such as heavy metals, or synthetic, such as some pesticides. They may be persistent or dissipate quickly. The key is that their effects result from very low dosages and often are cumulative so that the consequences to not emerge until some time after exposure.

In 1986, 16 states reported that toxic substances or some aspect of toxic substance control, is an issue of special concern, figure 1.6.

The problem of controlling toxics is particularly troublesome because of the Nation's dependence upon products that may contain hazardous substances or lead to the creation of hazardous substances. Over 60,000 commercial chemical substances are currently in use in the U.S. More than 50,000 pesticide products have been registered since 1947. About 3.5 billion pounds of formulated pesticide products are used by society each year. The benefits created by using these products in everyday life is substantial, so a wholesale retreat from their use is unlikely. Therefore, the key is to prevent misuse of these products and avoid releases resulting in environmental degradation and health risks, and to clean up those sites and waters that have already been contaminated.

Recent advances in monitoring and analytical precision have allowed a much more detailed description of trace elements in surface waters than available even a decade ago. Although no long-term records exist, short-term records frequently show increasing trends in the dissolved forms of two potentially toxic heavy metals--arsenic and cadmium. The dissolved forms are of particular concern because they can enter potable water supplies more readily than suspended materials. Increasing trends in arsenic and cadmium concentrations occurred with greatest frequency in watersheds in the Lake States and northern Great Plains. Evidence suggests that increased atmospheric deposition of fossil-fuel combustion byproducts was the predominant cause of the trends in both elements (Smith and others 1987). Runoff from fly-ash storage areas near power plants and nonferrous smelters is the other typical way that combustion byproducts enter surface waters. Other sources of arsenic and cadmium entering waste streams include primary metals manufacturing and plating, pesticides, herbicides, and phosphate-bearing commodities such as detergents and fertilizers.

Figure 1.6--States reporting control of toxic substances as a special concern



In contrast to arsenic and cadmium, concentrations of dissolved lead have decreased across the Nation. The principal areas of decrease are the heavily populated areas of the East and West coasts, and along the Missouri and Mississippi Rivers. The decline is due to the shift from leaded to unleaded gasoline. The consumption of leaded gasoline declined 67 percent between 1975 and 1981. In addition, the lead concentrations in leaded gasoline also declined in the same period. Declines in airborne lead have been reported for many U.S. cities. The exceptions to the observed decline of lead in streams and air are the Ohio and Great Lakes water resource regions. Although leaded gasoline consumption declined in these regions too, lead concentrations in streams did not. Unknown factors related to the solubility and transport of lead have influenced lead concentrations in streams in these regions.

Urban stormwater runoff is a major source of heavy metals entering surface waters. Concentrations of some heavy metals can be higher in street sweepings than in naturally occurring soils, rocks, and sediments, table 1.6. Shale was selected as the rock for comparison because it is a sedimentary rock and represents the naturally occurring concentrations in the absence of human influences. All of the metals in the table are used in common industrial processes or in domestic materials.

Table 1.6--Average concentrations of heavy metals in street sweepings compared to shale.

Heavy metal	Street sweepings[1]	Average of shale[2]
	--parts per million--	
Cadmium	3.4	0.3
Chromium	211	100
Copper	104	57
Iron	22000	47000
Lead	1810	20
Manganese	418	850
Nickel	35	95
Zinc	370	80

[1] Bradford (1977)
[2] Krauskopf (1967)

Pesticides, which include insecticides and herbicides, are applied extensively to crop, pasture, and forest land throughout the Nation. In urban areas, they are used on lawns, gardens, and to exterminate pests in buildings and homes.

Pesticides in runoff from cropland have been investigated, but little work has been done on pesticide residues and other organic substances in urban runoff, although significant concentrations of many of these substances have been measured in urban runoff.

Because of the wide variety of pesticides in use, the diversity of application from place to place, and the complexity of the processes which control the amounts of these substances washing from agricultural land, studies attempting to quantify pesticide concentrations in streams from particular land uses or land applications have proven fruitless (Anon. 1984). However, some broad patterns have been recognized in relationships between application, chemical properties, and losses from the soil of certain pesticides in common use (Wauchope 1978).

The greatest release of pesticides has been on farms (Eichers and others 1978), of which about 98 percent was applied to crops and 2 percent to livestock. Corn, cotton, wheat, sorghum, rise, other grains, soybeans, tobacco, peanuts, alfalfa, other hay and forage, and pasture and rangeland accounted for 85 percent of the pesticides used on crops. Nationally, the total volume of insecticides used annually is shrinking--largely because new products are more potent and thus applied at lower rates. Less than 100 million pounds of insecticides are applied annually to crop, pasture, range, and forest land. For example, since 1976, fenvalerate and permethrin use on cotton at very low application rates have largely replaced toxaphene and methyl parathion, which were applied at much higher dosage rates to obtain equivalent protection. Nationally, the total volume of herbicides applied to crop, pasture, range, and forest land has been increasing--from 100 million pounds in 1966 to 500 million pounds in 1982. These poundages do not include the quantities applied in urban and suburban areas, primarily by homeowners.

Organochlorine insecticides, such as DDT, chlordane, and dieldrin, are strongly adsorbed by soil particles and enter surface waters as a result of soil erosion. The use of these products has been largely banned, but because they are so resistent to decay, they continue to be found in stream sediments. From 1975 to 1980, the Pesticide Monitoring Network (Gilliom 1985) found traces of organochlorine pesticides in more than half the streambed sediments sampled but in less than 5 percent of the water samples. Historically, toxaphene, methoxychlor, DDT, and aldrin were the most heavily used, consequently, they should show up in samples most frequently. But the available tests for toxaphene and methoxychlor are the least sensitive of the tests for all organochlorine pesticides. Thus, they are seldom found. DDT and aldrin break down rapidly, so they are rarely detected. The products of their degradation, however, are found frequently. In contrast to these more heavily used compounds, lindane has been used relatively little, and yet was the most frequently detected organochlorine in water. The combination of lindane's relatively high solubility, high persistence, and easy detection explains this result. Because lindane is one of the products recommended for use in control of the southern pine beetle and given its properties just cited, care is needed to keep it out of surface waters. Chlordane was one of the most common termiticides used to treat building foundations. From a quantity standpoint, it was about as popular as lindane. Because chlordane is only one-third as soluble as lindane, it is almost never found in water samples. Yet, it is

prevalent in stream sediments. Thus, the patterns of detection that would be expected from use data alone do not occur because of varying chemical properties and analytical capabilities.

Organophosphate insecticides are highly soluble in water and usually last only days or weeks before degrading. Although they do not accumulate in organisms, they are more acutely toxic than organochlorine insecticides. Examples of these pesticides, also known as carbamates, are malathion and diazinon. Because they are so soluble in water, they are able to dissolve readily and move off the land surface as runoff or infiltrate the soil surface and move to groundwater if precipitation occurs while they are still active. Because of their high solubility and short life, they were very rarely detected in stream sediments, although they were detected in 5 percent of the stream samples taken between 1975 and 1980. Of the organophosphates, only diazinon use is increasing. Methyl parathion was used in the largest quantities, mainly on cotton. No trends are evident in pollution by organophosphate insecticides on a national scale.

Chlorophenoxy and triazine herbicides account for the third major category of pesticides. Atrazine and 2,4-D are responsible for most of the five-fold increase in herbicide use in the past 25 years. But by 1980, use was shifting from them to some of the newer products that are used in much smaller dosages. Data from the Pesticide Monitoring Network show virtually no detections of herbicides in streambed sediments and, except for atrazine, few detections in water samples. Atrazine was found in roughly 5 percent of water samples, the chlorophenoxys in 0.2 percent of samples or less (Gilliom 1985). Atrazine is widely used on corn--most samples where atrazine was found were downstream of major corn-production areas. 2,4-D alone, and in combination with related products, is widely used in granular and liquid formulations for turf management in residential and recreational settings (e.g. golf courses and parks).

In the 1950s and 1960s, chlorophenoxy herbicides were very popular for forestry applications. In the 1970s and early 1980s, new products were introduced that are more selective, have modes of activity that are less toxic to animals, and are available in formulations that are less likely to drift or drain out of the target area. Triazine derivatives and 2,4-D are still popular, but new families of herbicides, such as the sulfonated ureas, have become quite popular. When applied according to registrations and label directions, they have a very low probability of contaminating streams and aquifers.

Other toxic organic chemicals not used in land management have also entered the aquatic environment. The most significant of these are polychlorinated biphenyls (PCBs). PCBs typify compounds used in production of goods and services in the economy that are then disposed of when their usefulness is exhausted (among other things, PCBs are used to cool electrical transformers). Environmental Protection Agency (1987) reviews some cases where PCB contamination of stream sediments has led to moratoria in 15 states on consumption of fish caught in streams below points of known PCB discharges.

Because many toxics are long-lived, disposal of wastes and sediments contaminated by toxics is a major problem. Hazardous waste in groundwater was

mentioned as a problem by 39 States and in surface water by 16 States in Anon. (1984). Groundwater contamination by toxics is regarded as a more serious threat than surface water contamination because groundwater pollution is much more difficult to treat. Consequently, preventing toxics from entering groundwater is the major emphasis of toxic waste disposal. The Comprehensive Environmental Response, Compensation, and Liability Act of 1980, referred to as the "Superfund" legislation, established procedures for EPA to identify abandoned hazardous waste sites in need of remedial cleanup action. By 1982, EPA had selected more than 400 sites for action and initiated cleanup measures. The list is updated regularly with sites added and deleted as appropriate. The Resource Conservation and Recovery Act of 1976 gave EPA the authority to regulate the disposal of newly generated hazardous materials. As part of this process, the agency has identified 14,000 hazardous-waste disposal sites in across the Nation. These sites are carefully tracked as potential point-sources of pollution.

Resource Management Externalities Affect Water Resources

When pollutants generated at one place move off-site and affect stream ecosystems or downstream water users, the off-site effects are called **externalities**. Although externalities may create benefits free of charge, the more likely scenario is that externalities create uncompensated costs. The key to creating externalities is that off-site effects to others do not enter the decision process of the one making the initial resource management decision. For example, where soils are saline, irrigators periodically apply extra water to dissolve the salt and flush it out of the crop rooting zone. The salt-laden irrigation return flows move downstream, where other irrigators reusing the water must either use more water to avoid salt accumulations in their fields or crop damage from the salt. Using more water costs money and so does crop damage--neither cost is borne by the upstream water user who put the salt into the water.

The standard solution to an externality problem is to find a way to make the party creating the damage bear the full costs of the action taken. One of the characteristics of externalities is that it is not usually possible to assign responsibility to a particular action or landowner. Rather, the best that can be done is assign responsibility to a certain class of actions or group of landowners. This characteristic complicates solving the externality; it means that some level of government must regulate the activities causing the off-site damages.

The purpose of this section is to outline three major water resource problems and illustrate how externalities contribute to them. The first is acid deposition. Emissions of certain byproducts of combustion processes to the atmosphere create externalities when those airborne emissions undergo chemical reactions and are subsequently deposited on downwind sites. When the sites receiving the deposits are at high elevations and ecosystems are fragile, the externalities pose significant environmental problems for water resources. The second case is erosion. When sediments and related materials, such as nutrients, pesticides, and organic acids, flow off a site and into streams, there are adverse impacts on stream ecology and downstream water users. The

third case is groundwater contamination from land management. Contamination most commonly arises from improper water management, although it can arise from many different, normal, land management activities. Municipal, industrial, and livestock waste disposal each have the potential to alter the chemical composition of groundwater. All three of these problems stem from externalities that are forms of nonpoint-source pollution. Yet each presents special problems for regulators because of the nature of the pollution and its effects on other water users.

Acid Deposition[10]

Description and Sources—Acid deposition is a comprehensive term incorporating precipitation of acids in rain and snow; contact of acidic clouds, dew, and fog with the land and vegetation; and dry deposition of solid and gaseous acid precursors. The major acids involved are sulfuric and nitric. Neither of these acids is emitted directly into the atmosphere in significant quantities. Rather, they are formed in the atmosphere by the oxidation of sulfur dioxide, nitrogen oxides and a variety of volatile organic compounds by a number of atmospheric oxidants.

Sulfur dioxide is emitted primarily by combustion of coal and heating oil containing high amounts of sulfur and by metal smelters. Coal-fired electric generators are the largest source of sulfur dioxide in the East and the second-largest source in the West. The Ohio water resource region contains a high percentage of older powerplants that have historically used high-sulfur coal. In the West, metal smelting is the largest source, accounting for half of all the sulfur dioxide emissions (Roth and others 1985). Denton (1987) reported that, according to Canadian authorities, the Inco smelting facility in Canada was responsible for 3 percent of the total North American emission of sulfur dioxide, on an annual basis. According to EPA in 1977, stationary fuel combustion was responsible for the largest share of sulfur dioxides (20 percent) and nitrogen oxides (13 percent).

Nitrogen oxides are emitted primarily by motor vehicles and to a lesser extent, by electric utilities. In the West, motor vehicles contribute half of all the anthropogenic nitrogen oxide emissions.

Volatile organic compounds are released during petroleum refining, chemical manufacturing, paint and solvent use, and transportation. Industrial processes emitted the largest share of volatile organic compounds (10 percent) and also contributed the biggest share of suspended particulate (5 percent). Transportation was responsible for 85 percent of the carbon monoxide emissions.

The chemical transformations of sulfur dioxide and nitrogen oxides into acids can occur in clear air or in clouds, near or far from the point of emission. Eventual deposition is influenced both by prevailing meteorological conditions and surface characteristics. The chemical transformations of sulfur dioxide and nitrogen oxides into acids requires intervention of oxidants in the atmosphere. Oxidants, in turn, are the result of the interaction of volatile organic compounds with nitrogen oxides in the presence of sunlight. One of the most important recent findings in atmospheric chemistry is that oxidant

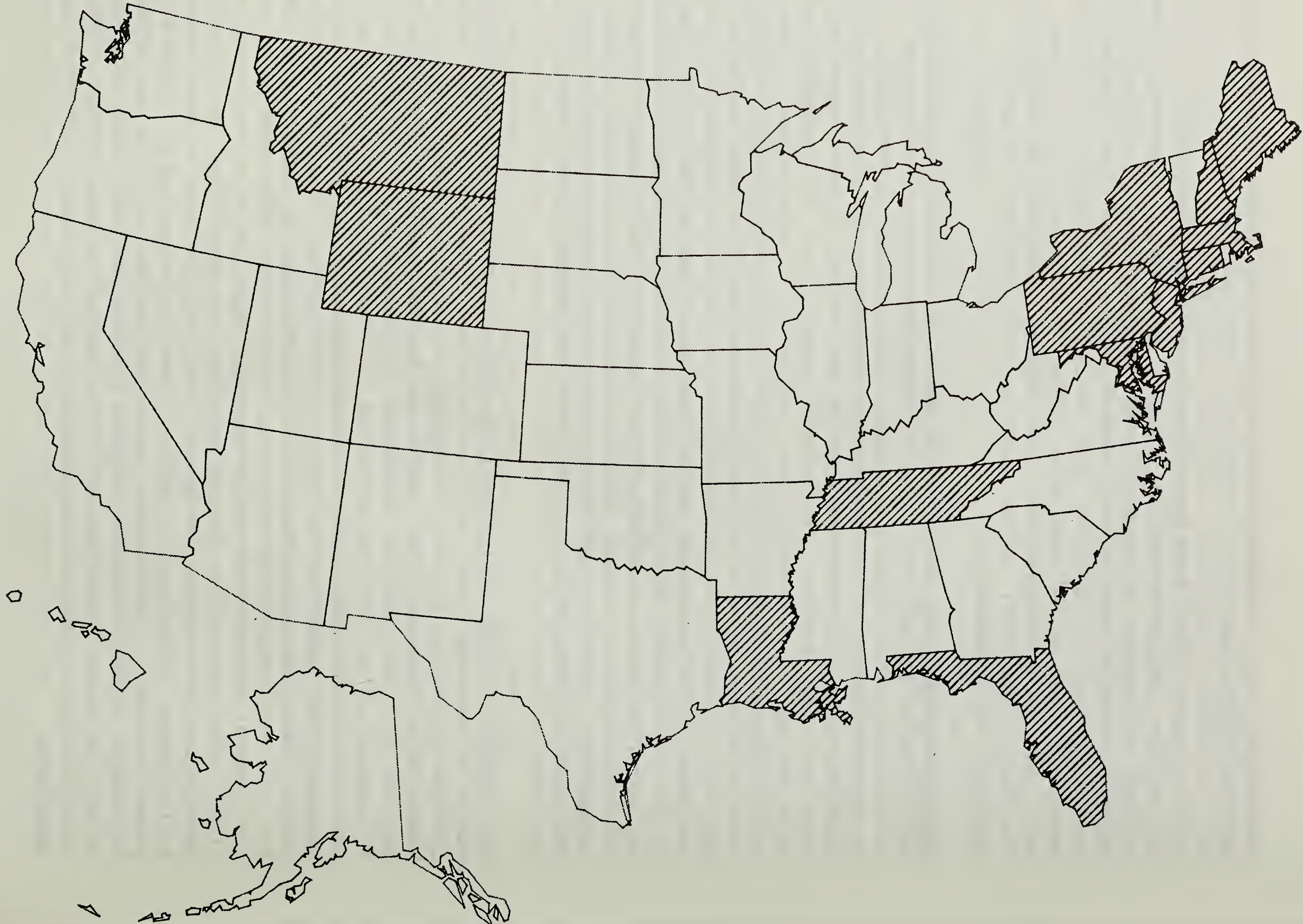
availability may limit the production of sulfuric acid, at least during some portions of the year.

Thirteen states cited acid deposition as an issue of special concern in their 1986 Section 305(b) reports, figure 1.7. In general, states cite lowered pH of rainfall as evidence of potential problems even though the effects of acid deposition remain uncertain and unquantified. Nonetheless, factors other than rainfall pH must be considered when evaluating the impacts of acid deposition. Perhaps the most significant other factor is the geology of the area. Some soils and rock formations have a few natural carbonates to neautralize acidity ("buffering capacity"), while others are soils and rock formations are generally well buffered.

<u>Linkages to Other Air Quality Problems</u>--It is important to note that while acid deposition is normally viewed as an independent issue, the chemical changes occurring in the atmosphere are inextricably related to one another. Problems of ozone depletion, visual impairment, "greenhouse warming," and acid deposition are all interconnected with one another to some degree and all are associated with changes in atmospheric composition. For example, the gases which are predicted to modify the distribution of stratospheric ozone (i.e. carbon monoxide, methane, nitrous oxide, and chlorofluorocarbons) are the same gases which are infrared active (greenhouse gases) and are predicted to warm the Earth. In addition, increasing concentrations of methane are also predicted to increase ozone in the troposphere and may be responsible for some of the forest damage that is occurring. Increased atmospheric levels of sulfur may possibly influence climate through enhanced levels of sulfate aerosols. Oxides of nitrogen strongly influence the production of ozone in the troposphere. Many of these same chemicals and byproducts of the chemical reactions are responsible for the gases and aerosols that create visual impairment.

<u>The Mandate to Study Acid Deposition</u>--The government conducted a review of the status of knowledge about acid precipitation in the 1970s. That review resulted in passage of the Acid Precipitation Act of 1980 (Title VII of the Energy Security Act of 1980, Public Law 96-294) and establishment of the National Acid Precipitation Assessment Program (NAPAP). NAPAP is an interagency effort with the objective of conducting a ten-year research program crucial to understanding the processes involved in acid deposition and assessing their quantitative impacts on ecosystems. In cooperation with the states, NAPAP has constructed a detailed inventory of anthropogenic emissions for 1980 and is currently developing one for 1985. This inventory concluded that natural emissions of sulfur are small relative to man-made ones. Dampier (1982) noted that sulfur dioxide emissions are much higher in the northern hemisphere than southern hemisphere (145.5 million tons per year versus 5.5 million tons, respectively), and are steadily increasing at the rate of 5 percent annually. Considerable uncertainty exists regarding the relative importance of natural versus man-made nitrogen sources. Some estimates of natural emissions range from 8 to 30 percent of man-made levels. Natural volatile organic compounds emissions are believed large relative to man-made emissions.

Figure 1.7--States reporting acid deposition as a special concern



The general geographic pattern of precipitation acidity has changed very little since extensive monitoring began in 1978. Rain and snow acidity for 1985 was highest in the northeastern U.S. The lowest acidities, below pH 4.2, were found in the upper Ohio River Valley of eastern Ohio and western Pennsylvania, extending across the Canadian border into southcentral Ontario. Precipitation monitored at remote sites generally has a pH between 5.0 and 5.5 (Roth and others 1985). Precipitation pH below 5.0 is generally taken as indicative of anthropogenic influences. Roth and others (1985) note that the amount of deposition measured in precipitation is typically doubled to account for the latter two types of deposition when estimating total deposition load. But it is not known whether or not this rule of thumb is adequate for more arid western locales where most precipitation falls as snow in the winter.

Implications for Aquatic Ecosystems--Lake and stream acidification, which can damage aquatic organisms, may result from natural and man-made causes. Surface water chemistry can change either over the long term or during short episodes, such as the spring melting of snowpack. Budiansky (1981) noted that the greatest pH shock to lakes occurs when snow melts and runs off in the spring. Soil type, hardness of the winter freeze, and amount of dry deposition, together with type and amount of snow and ice, all determine the amount of acidic material that has accumulated over winter and the portion of it likely to be absorbed by the soil, given its buffering capability. The larger the portion of annual precipitation that falls as snow and the lower the soil buffering capability, the greater the potential for damage due to a pulse of acidity entering a waterbody during snowmelt. Roth and others (1985) note that springtime acid pulses from snowmelt can severely harm sensitive aquatic ecosystems even if the ecosystems do not permanently acidify.

Middleton and Rhodes (1984) concluded that acid deposition has the potential to contribute to drinking water toxicity. Raw drinking water that is acid can free toxic metals, such as aluminum, from the chemical bonds normally immobilizing them to soil colloids. If not adequately neutralized as part of water treatment, the acid remaining in the water can dissolve toxic metals, such as lead, from water distribution pipes. Because of the number of areas in the northeastern U.S. using surface water sources for drinking water supplies, Middleton and Rhodes believed the extent of the impact could be considerable. Water treatment processes exist for dealing with acidity in raw water and for removing toxic metals during water treatment, but they are more costly than conventional treatments.

Analysis of historical records by the National Academy of Sciences shows no net acidification of lakes in the past 50 to 60 years in either Wisconsin or New Hampshire, although a few high elevation lakes in the Adirondack region of New York may have suffered some increased acidification. The study noted that quantifying the amount of acidification was not possible at this time. Our understanding of how acid deposition interacts with individual biological, geological, and chemical processes in watersheds and surface waters is considerable. However, major uncertainties exist in how the individual processes work together individually and over broader areas to result in observed surface water chemistry, according to Council on Environmental Quality (1987).

New York and Canada allege a much greater impact on high elevation lakes than determined by the National Academy of Sciences. New York considers damage to some 500 lakes in the 6-million-acre Adirondack Forest Preserve to be catastrophic (U.S. Department of Agriculture 1987). About 2 million acres in the Catskill area are also reported to be affected, but to a lesser extent. By Canada's count, 13 salmon-bearing lakes and 14,000 other lakes in eastern Canada are incapable of supporting fish life (Denton 1987). Studies cited by Roth and others (1985) report that between the 1930s and the 1970s, the percentage of lakes in the Adirondacks with pH less than 5.0 increased from 8 percent to 48 percent and the percentage with no fish increased from 10 percent to 52 percent. In New England, a study of 95 lakes for which there are historical pH data showed an average alkalinity decrease of 100 milliequivalents per liter between the 1930s and 1960s.[11] Likens (1976) found a clear correlation between geographic areas where precipitation is particularly acidic and areas where lake acidification has occurred. Evidence that other mechanisms could have caused acidification is less convincing.

Roth and others (1985) summarized the prevailing hypotheses about how lakes and streams subject to acid deposition lose fish populations. Chemical reactions mobilizing aluminum, found in most watershed soils, that are dependent upon low pH are identified as the primary culprit. Laboratory studies have shown that fish are injured directly by low pH and indirectly when concentrations of toxic metals, such as aluminum, result. Both combine to cause reproductive failure in fish and also in organisms in the fish's food chain. The low pH and metal concentrations are thought to be more damaging to aquatic organisms in the spring, when many are in early developmental stages. This coincides with onset of snowmelt. Roth and others (1985) report that the effects of partial acidification, due to presence of some natural alkalinity, are less well understood.

Implications for Forests--Observations of diminished growth in southern softwoods at low elevations and of visually apparent deterioration of spruce-fir forests at high elevations have heightened concern over the causal factors, and the possible role played by air pollution generally, and acid deposition in particular. Budiansky (1981) said that the real question is how the entire forest responds when perturbed by pollution. He noted that the major problem facing vegetation in the Northeast may not be acid precipitation or sulfur dioxide, but ozone. Williams and others (1977) found widespread damage to Ponderosa pine, apparently from ozone, in dry regions downwind of Los Angeles and Central Valley. The injury suggested that trees growing in a relatively dry habitat on sensitive soil may be subject to direct damage from air pollution, possibly including acidic deposition interacting with ozone and other pollutants (Roth and others 1985).

However, given our current state of knowledge about forests, scientists are not yet able to show that changes in acid deposition would result in changes in forest growth or other measures of forest vigor. The problem is a complex one, involving linked chemical, physical, and biological systems and requiring a comprehensive, interdisciplinary approach. Current research involves efforts to explain observed forest changes by systematically testing a long list of hypotheses including: natural cycles, climate change, pests and disease, forest stand history effects (e.g. exhaustion of residual fertilizer nutrients from

previous agricultural use of the land), land management practice effects, and air pollution and acid deposition. Three short excerpts are presented below. Taken together, they portray the diversity of views currently held about the impact of acid deposition on forested ecosystems and tree growth.

> Woods (1987) noted that the long-term effects of acid deposition on soils include making elements normally bound by soil particles--such as aluminum ions--more available for plant uptake. Aluminum ions can be concentrated in plant roots to concentrations where they are toxic to the plants. They also reduce the availability of calcium. All these changes lead to nutrient imbalances in plants, which can cause reductions in productivity well before toxicity causes death. Even small changes in the physiology of trees can cause losses in forest growth. Trees are vulnerable because of their long growth cycles. Conifers are especially vulnerable because needles persist for two to four years and so are exposed longer to atmospheric deposition.

> Brown (1987) noted that the amount of acidity generated by natural sources in the eastern U.S. is much greater than for acid rain. Animal waste and decaying vegetation are responsible for many soil acids. Heavy rains wash these acids into rivers and streams before they can be neutralized by deeper soil layers. Any unusual damage to forests are more likely to stem from combinations of natural stresses, such as droughts, frosts, insects, and pathogens coupled with the impact of various air pollutants. Ozone may be a contributor to the problem.

> Johnson and Siccama (1983) noted that the available evidence does not show a clear cause and effect relationship between acid deposition and forest decline and dieback in the U.S. Given the lack of other causal agents and the characteristics of the observed dieback, it appears that the mortality is probably related to some environmental stress or combination of stresses. Their statistical analyses showed that mortality was only significantly correlated with elevation. Several stress factors are related to elevation; it is not currently possible to determine which factors are relevant. Wind speed, exposure to cloud moisture, hydrogen ion concentration and the heavy-metal content of the soil all increase with elevation. Drought stress in combination with predisposing factors related to site conditions has triggered forest declines in the past. Johnson and Siccama suggest that the growth reductions in red spruce during the mid-1960s represent initiation of dieback and decline in these trees. The early and mid-1960s were a period of drought in the Northeast. Available information does not suggest that either sulfur dioxide or ozone plays a major role in the spruce decline. Other studies cited by Johnson and Siccama support drought as a prominent factor in observed forest diebacks in North America and Europe.

Erosion

The off-site impacts of sediment were identified in the Appraisal as one of the most significant impacts created by agricultural land management practices on non-federal lands. Erosion reduction is the major focus of the National Conservation Plan currently being developed by the SCS in response to the Appraisal. It is also one of the primary water-related impacts of forest and rangeland management on federal lands.

Clark and others (1985) focussed specifically on the off-farm impacts of erosion, measured largely by the effects of sediment on water use. The study examined the problems caused by sediment and other contaminants carried off by storm water after leaving eroding fields. They found that sediment causes a variety of instream and off-stream damages influenced by a complex set of hydrological, physical, chemical, and biological interactions. Christensen and Ribaudo (1987) updated the economic estimates of erosion damage made by Clark and others (1985). Christensen and Ribaudo (1987) estimate that sediment in water causes $7.1 billion in damages annually, of which cropland's share is $2.6 billion.

Instream damages are caused by sediment, nutrients and other erosion-related contaminants in streams and lakes. They include damages to aquatic organisms, water-based recreation, water-storage facilities, and navigation. Offstream damages occur before sediments reach a waterway, during floods, or after water is diverted from a waterway for use.

Biological Impacts of Erosion--Aquatic ecosystems are affected in a variety of ways, generally related either to reproduction or respiration. Sediment destroys spawning areas, food sources, and habitat as well as directly damaging fish, crustaceans, and other aquatic wildlife. Algal growth stimulated by nutrients blocks sunlight while the algae are alive; when dead, algal decomposition strips dissolved oxygen from the water rendering respiration impossible. Pesticides and other contaminants carried off agricultural lands can be directly toxic to fish and to organisms lower in the food chain. Clark and others (1985) identified agricultural runoff as chronically affecting fish communities in 30 percent of the nation's waters, and fish kill reports have identified such runoff as a major cause of acute episodes.

Although some of these biological impacts are reflected in damage estimates to recreational and commercial fishing, the overall magnitude of impacts cannot presently be measured because the methodology is not available. This is not to say that damages are small or nonexistent; could they be measured, they might well outweigh any of the others.

Recreational Impacts of Erosion--All types of water-based recreational activities are adversely affected by erosion-related pollutants. The value of freshwater fishing is reduced because of the demise of valued species and reductions in fish populations. Fishing is also less successful in turbid water because the fish have difficulty seeing lures. Many of the same problems affect marine recreational fishing. Many marine species reproduce in estuaries and rivers. As the deterioration of the fisheries of the Chesapeake Bay amply

demonstrates, eroded sediments and excess nutrients can lead to severe reductions in fin and shellfish populations.

Boating and swimming are also affected because weed growth and siltation physically interfere with recreational activities. Hunting is also affected because many waterfowl depend upon aquatic vegetation and other affected aquatic wildlife for food. The total economic cost of these recreational damages was estimated by Christensen and Ribaudo (1987) at $1.889 billion per year and $544 million for marine fishing.

<u>Erosion Damages to Water Storage</u>—Damage to reservoirs from sediment are measured by the increasing cost of building and maintaining water-storage capacity. An estimated 1.4 to 1.5 million acre-feet of reservoir and lake capacity is permanently filled each year with sediment. Recent construction of new storage capacity averages 1 million acre-feet annually at a cost of $300 to $700 per acre-foot. Not only is the Nation failing to keep up with the rate of sedimentation, but costs of providing additional storage in the future are increasing because all the low-cost dam sites have already been utilized.

Sediment and nutrients affect the rate of evaporation and transpiration from water bodies. Evaporation is a particularly serious problem in arid regions because more than an acre-foot of storage has to be constructed to provide an acre-foot of yield. Here, suspended sediments and algae may provide a benefit because they reflect much of the solar energy that would otherwise warm the water and enhance evaporation. However, the sediments and nutrients are a two-edged sword because they also increase the rate of transpiration by stimulating the growth of water-consuming vegetation in shallow areas of the lakes.

Lake cleanup is a final cost related to water storage. Lakes are the only water bodies that have suffered a net decline in water quality since 1975. All levels of government are spending substantial amounts for weed control and other cleanup activities. The total annual cost of all these impacts on water-storage facilities is estimated to be $1.097 billion (Christensen and Ribaudo 1987).

<u>Impacts of Erosion on Navigation</u>—Sedimentation affects navigation in diverse ways. The major economic cost is maintenance dredging of harbors and waterways. The major environmental cost is disposal of dredged spoil. Prior to the 1950s, spoil was typically disposed of by filling wetlands for further urban development. This practice has largely ceased. Coastal dredged spoil was often barged to sea and disposed offshore. In either case, the dredging process causes temporary turbidity plumes from the site downstream. If these coincide with critical reproduction times, the effects can be just as severe as longer term turbidity. Other costs include accidents and shipping delays. The costs of these impacts is estimated to be $680 million annually (Christensen and Ribaudo 1987).

<u>Other Instream Impacts of Erosion</u>—Soil erosion also can damage commercial fisheries and reduce preservation/option/bequest values. Commercial fisheries suffer from the same problems as recreational fisheries. The latter values represent the benefits people place upon clean water even though they may never make direct use of the water body. Some studies have shown these latter values

to be even higher than recreational and other user values. The total cost of these two types of damage was estimated by Christensen and Ribaudo (1987) to be $409 million for commercial fishing. Estimates of the damage to preservation/option/bequest values is not currently estimable with the same accuracy as the other damages. Comparing Clark and others (1985) and Christensen and Ribaudo (1987), perhaps up to $600 million in damages to these values occurs annually.

<u>Flood Damages of Erosion</u>—Sediment contributes to flood damages in three ways. First, by settling out in streambeds and clogging waterways, it increases the frequency and depth of flooding. Second, because suspended sediment is carried by flood water, the volume of the water/soil mixture is increased, raising flood crests. Third, many flood damages are caused by sediment, not the water itself. There may be long-term damages to agricultural land if floods leave behind infertile silt. The total of all these damages was estimated by Christensen and Ribaudo (1987) to be $888 million per year.

<u>Water-Conveyance Impacts of Erosion</u>—Some of the sediment settles out in drainage ditches before water reaches streams. Clark and others (1985) cited estimates from Illinois that highway department crews remove from drainage ditches annual an amount of sediment equal to 1.4 percent of the total erosion occurring in the state. The annual cost of controlling weeds and removing sediment from the 110,000 miles of irrigation canals in the U.S. accounts for 15 to 35 percent of annual canal maintenance costs. The total cost of these damages is estimated to amount to $214 million per year (Christensen and Ribaudo 1987).

<u>Water-Treatment Costs of Erosion</u>—The cost of treating water before municipal or industrial uses increases when raw water is turbid. Sedimentation basins must be built and periodically cleaned out, chemical coagulants must be added, filters must be cleaned more frequently, and special treatment apparatus installed to handle nutrients and other contaminants. For example, nutrients and algae may clog heat exchanger tubes in steam boilers or cooling towers, necessitating increased maintenance costs. Christensen and Ribaudo (1987) estimated that these procedures cost $1.231 billion annually.

<u>Other Offstream Impacts of Erosion</u>—Often, water contains sediment or agricultural byproducts, such as dissolved salts, in concentrations that are too small to justify treatment. Yet these constituents of the water cause increased operations and maintenance costs and more frequent replacement irrigation equipment. Salt and alkali buildups in pipes can lead to added maintenance and replacement costs. Irrigators using turbid water experience increased costs and reduced yields if fine silt causes a crust to form on the soil surface, impeding water infiltration and seed germination. Christensen and Ribaudo (1987) estimated that the net cost of all these other off-stream impacts at $135 million annually.

<u>Summary</u>—The total estimate of erosion-related damages is $6.1 billion annually, of which $2.2 billion is attributable to cropland. If sediment damages are isolated from nutrient, pesticide and other erosion-related damages, the totals are $3.5 billion; $1.2 attributable to cropland.

Erosion-related damages not attributable to cropland fall into two categories. The first is erosion from other land management practices. Examples are construction, forestry, grazing, and mining operations. Forestry activities having high erosion potential include road building, timber harvesting operations and wildfire. Overgrazing is the primary source of erosion from rangelands. The Appraisal found that at present, 20 percent of rangeland has erosion exceeding T[12]. The Appraisal concluded that erosion on rangeland is a potential problem on 61 percent of non-federal range. The assumption made when evaluating this potential was that all range in less than good condition is susceptible to damage. The watershed condition class discussion earlier in this chapter pointed out that 72 percent of watersheds in the sample are either in the Special Emphasis class, needing careful management to avoid problems, or in the Investment Emphasis class, needing technological and economically feasible investments to restore watershed conditions to a level consistent with watershed management goals. The most significant factor placing these forests and rangelands at risk is the potential for erosion and movement of sediment off-site.

The second category of erosion-related damages not attributable to cropland comes from sediment deposits currently in streams. In some areas where erosion was formerly a major problem, such as the abandoned cropland in some parts of the South, streams no longer carry the fresh sediment loads they did at the turn of the century. As sediments have been prevented from entering the streams either by conversion of the land to forests or more enlightened land management, the water energy formerly used to carry sediments has begun scouring old sediment deposits from stream channels and carrying these previously-deposited sediments downstream. This action of the water has confounded many studies seeking to demonstrate that land management activities have had direct effect on reducing instream sediment concentrations, because little reduction in sediment in the water has been observed. In some streams, long-buried bridges and other historical artifacts are reemerging from the silt, offering historians fresh opportunities for studying pioneer and plantation life of the 1700s and 1800s. It may take another 50 to 100 years for these entrained sediments in stream channels to be scoured out and the streams to return to the channel configurations they enjoyed before development began.[13]

Clark and others (1985) concluded that developing an effective, efficient program to control off-farm impacts of eroded materials would be difficult. They called for new regulatory programs that were more accurately targeted at erodible soils and land management practices insensitive to them. A key element they identified was taking the most seriously eroding lands out of row-crop production or out of production altogether. Following close on the heels of their book, Congress passed the Food Security Act of 1985. It contained a section dealing with soil conservation measures, having several provisions that respond quite closely to the conclusions reached by Clark and others (1985). Four notable provisions to reduce cropping of erodible land and the environmental implications of land management were (1) creation of the Conservation Reserve Program (CRP), (2) the Conservation Compliance provision, and (3) the "Sodbuster" provision, and (4) the "Swampbuster" provision. These provisions only apply to lands with the potential to erode more than 8 times faster than new soil can be regenerated. There are 118 million acres of such

soils in the U.S., 35 million of which are being managed to prevent erosion in excess of the rate of regeneration (Reichelderfer 1987).

The lands farmers nominate to join the CRP must be planted to grasses, trees, or shrubs following a conservation plan prepared for the acreage. After planting, the land cannot be used for any commercial purpose, including grazing, for a decade[14]. The federal government pays half the cost of establishing the grasses, trees, or shrubs and also an annual rental payment for the 10-year CRP contract period. The average annual payment was $46 per acre in 1986 (Reichelderfer 1987). The objective is to entice farmers to take marginal farmland out of production by providing an alternative annual return whose net return to the farmer is greater than the net return from cropping. In the first year of enrollments, more than 8 million acres joined the CRP. Reichelderfer (1987) estimates that 40 to 45 million acres will be enrolled in the CRP by 1990.

The conservation compliance provision is designed to keep erosion low on erodible lands currently being farmed. Failure to do so causes the farmer to forfeit the right to participate in other farm programs offered by the U.S. Department of Agriculture. This provision is aimed at the 35 million acres currently being farmed.

The sodbuster provision denies eligibility for U.S. Department of Agriculture programs to farmers who newly cultivate highly erodible land without using an approved conservation system. The swampbuster provision denies eligibility to farmers to convert wetlands to production of agricultural commodities. The latter two provisions are designed to discourage the conversion of grasslands and river bottom lands, predominately forest, to crop production.

Groundwater Contamination

Most groundwater supplies in the U.S. are of good quality. In some localities, however, contamination has caused well closures, public health concerns, and economic losses. These problems could spread. The challenge is to prevent localized problems from becoming local crises or regional problems.

The Conservation Foundation (1987) concluded that groundwater protection efforts have been partial, at best. The regulatory programs put in place often have failed to exercise much of the statutory authority available. Because many of the laws were written at different times and for different purposes, they often add up to a program of groundwater protection that is neither coherent nor consistent, even if those laws are implemented to the limits of enacted authority.

<u>Source and Scope of Groundwater Contamination</u>—Groundwater can be contaminated in a variety of ways. Environmental Protection Agency (1988) summarized major sources of groundwater contamination reported by states. More than 40 states reported septic tanks, underground storage tanks, and agricultural activities as major sources of contaminants. More than 30 states reported landfills, both municipal and private, lagoons, and abandoned waste sites as major sources of groundwater contamination.

Underground Storage Tanks--Underground storage tanks were listed as the primary source of groundwater contamination by 11 states: Alabama, Alaska, Florida, Michigan, Montana, New Jersey, New York, North Carolina, Pennsylvania, South Dakota, and Virginia. The Conservation Foundation (1987) provides additional detail on the magnitude of the problems associated with underground tanks, citing a recent Congressional Research Service report which estimated that there are between 5 and 10 million underground tanks of all kinds (EPA's estimate is 3 to 5 million), of which 1.5 million tanks contain petroleum or hazardous substances (1.4 million by EPA's estimate). Most existing tanks are made of carbon steel, unprotected from corrosion, ranging in size from 10,000 to 50,000 gallons. Some fiberglass tanks are also used, but they tend to be smaller, averaging 10,000 gallons. The Congressional Research Service estimated that 25 to 30 percent of the tanks containing petroleum products may be leaking (a limited EPA survey in 1986 found 35 percent). Vehicle filling stations accounted for the majority of the leak locations. Other studies found that the majority of leaks occur from operating tanks instead of abandoned ones and that leaks of solvents are more prevalent, percentage-wise, than leaks from petroleum tanks. Corrosion of tanks and associated pipes and fittings accounts for 90 percent of the leaks, according to the Conservation Foundation (1987).

Septic Tanks--Failure of septic systems was reported as the primary cause of groundwater contamination by nine states: Arkansas, Delaware, Illinois, Kentucky, Maine, Maryland, Nevada, Ohio, and Tennessee. Contamination from this source is not a new problem; however, shifts in housing patterns and land use, particularly increasing housing densities in suburbs, have made septic system discharges a more prevalent problem. About one-fourth of the homes in the U.S. (20 million homes) use on-site sewage disposal, most of them east of the Great Plains. Septic systems are far more popular than cesspools or pit privies. A 1980 study cited by Conservation Foundation (1987) reported that up to one-third of the systems were operating improperly. Groundwater pollution by nitrates, phosphates, heavy metals, other inorganics, and toxic organics, often used as system cleaners, result when the systems are not operating properly. The efficiency of a septic tank decreases over time, even with proper maintenance (periodic removal of sludge), because of a buildup of film on the outside of the drains or clogging of the drainage bed material. One study (Conservation Foundation (1987) found that 75 percent of septic system failures can be attributed to overloading the drain field with sludge. The cleaning and sludge removal process often uses chemicals, such as trichloroethane, benzene, or methyl chloride, to dissolve sludge in tanks and drain fields--chemicals that should not come in contact with groundwater. Widespread use of these chemicals on Long Island in 1979 (an estimated 400,000 gallons total, many applied by homeowners themselves) resulted in closure of many public and private wells (Conservation Foundation 1987). Careful location, construction, and maintenance provides some measure of protection against groundwater contamination.

Agricultural Activities--Agricultural activities were cited as the primary source of groundwater contamination by 6 states: Arizona, Arkansas, California, Connecticut, Hawaii, and Iowa. The primary contaminants are nutrients from fertilizers and livestock waste disposal and pesticides.

Fertilizer use in the U.S. has grown drastically in the U.S., rising 300 percent between 1960 and 1980. Nitrogen fertilizer applications have quadrupled over the same period. In addition to the large increases in fertilizer applications to cropland, large amounts are also applied in urban areas to turf and gardens. The Conservation Foundation (1987) recounts results of several studies in Wisconsin, Nebraska, and Iowa linking increases in nitrate concentrations in well water to heavy usage of nitrogenous fertilizers.

Animal wastes are another source of nutrients, and also bacteria. Feedlots are often viewed as major sources of contamination problems, but manure disposal on individual farms can also cause problems. Southeastern Pennsylvania is one of the most concentrated areas of dairy farms in the nation, supplying milk to the New York-Baltimore megalopolis. The volume of manure created and the small size of the typical dairy farm combine to create manure disposal problems. Application rates exceeding 2 tons per acre per year are not uncommon; at a 5 percent nitrogen content, this equates to in excess of 200 pounds of nitrogen per acre annually. Runoff from fields contaminates surface waters, and leachate percolates to groundwater. Because of the limestone geology of Southeastern Pennsylvania, there are many channels and solution cavities providing speedy access of percolate to aquifers which exacerbates the manure disposal problems there. The Conservation Foundation (1987) recites manure disposal problems associated with beef production in Colorado and poultry production in Delaware. Methods of solving nutrient contamination problems from agricultural operations include matching fertilizer requirements and timing of applications more closely with actual crop needs and collecting, storing, and treating livestock and poultry wastes before applying them to fields.

Pesticide applications were the second concern related to agricultural operations. The Conservation Foundation (1987) reported that herbicide use has grown the fastest--280 percent between 1966 and 1981--as chemicals replaced mechanical cultivation for controlling weeds. In 1982, 91 percent of all U.S. cropland farmed was planted with row crops, and 44 percent of those acres had herbicides applied. However, 85 percent of the herbicides and 70 percent of the insecticides were applied to only four crops--corn, cotton, soybeans, and wheat. The two most heavily used substances are the herbicides alachlor and atrazine, accounting for 25 percent of the total national usage. The two states using the largest quantities are Iowa and Illinois, accounting for 21 percent of total usage. Soluble formulations of pesticides and those products designed to kill soil pests have the greatest potential for contaminating groundwater. Problems with groundwater contamination can be minimized by using formulations that do not migrate through the ground, by taking greater care in where, when, and how pesticides are applied, and by combining pesticide usage with other non-chemical techniques in a program of integrated pest management.

<u>Landfills</u>--Five states identified landfills as the primary source of groundwater contamination. The Conservation Foundation (1987) estimated that between 15,000 and 20,000 municipal dumps and sanitary landfills exist in the U.S. An exhaustive list is not available; the actual number could be as high as 40,000. Four out of five of the facilities are small, handling less than

100 tons of waste daily. A total of 275 million tons of municipal solid wastes are disposed of in landfills annually. Older landfills and open dumps were often uncovered, unlined, and located with no consideration of their potential for contaminating groundwater. In addition, many landfills were located on marshlands, abandoned gravel pits, and old strip mines. Such sites are susceptible to groundwater contamination if infiltration flowing through the disposal site is a source of groundwater recharge and if the underlying soils are sufficiently permeable to allow leachate to enter the groundwater system. Percolation of leachate from landfills is inevitable unless the site is completely sealed on all sides. Few are. Groundwater contamination from landfills can be minimized by improved designs, construction, operation and maintenance. Design considerations should always include the hydrogeology of the location for the landfill, area to be served, and types of wastes. The use of liners and covers, as well as collection and treatment of leachate, further reduce the potential for groundwater contamination (Conservation Foundation 1987).

Hazardous Wastes--Hazardous wastes, while a major cause of concern by 29 states, were a primary concern of only 3 states. About 5,000 sites in the U.S. are treating, storing, and disposing of hazardous wastes. The largest number of sites are in the Great Lakes region, followed by the Southeast and Southwest. As of June 1986, 888 abandoned hazardous waste sites were listed or proposed for listing on the National Priorities List, and thus targeted for federally funded cleanup under the Superfund (Conservation Foundation 1987). Seventy-five percent of the sites on the National Priorities List have documented groundwater contamination problems. The most commonly found substances include trichloroethane, lead, toluene, benzene, PCBs, chloroform, phenol, arsenic, cadmium, and chromium. The potential for contaminating groundwater can be reduced in several ways. Careful siting and operation of treatment, storage, and disposal facilities can minimize the potential for unforeseen problems. Liners and leak detection systems can be installed to reduce the possibility that contaminants can escape unnoticed. Enclosing more hazardous substances in concrete, glass, or ceramic vessels reduces potential for leakage. Alternative disposal techniques such as incineration or waste solidification may have less environmental hazard than burial. Finally, reducing the generation of hazardous wastes through modifying plant processes, recycling, detoxifying, drying, or substituting nonhazardous materials should also be examined. These steps provide the most attractive long-term methods for reducing the problem (Conservation Foundation 1987).

A Groundwater Protection Strategy--The National Groundwater Policy Forum (Conservation Foundation 1987) concluded that the Nation must adopt a much more aggressive policy of groundwater management if the resource is to be adequately protected for current and future users. Because the problem is complex, a highly coordinated attack is required with participants from all levels of government and industry. Partnerships must be forged to achieve the common goal of protecting the groundwater resource. Four principles should guide the development of a protection strategy: (1) active management is required to meet human and ecological needs; (2) contamination should be prevented wherever possible because of the technical difficulties and costs of cleanup; (3) degradation of the most valuable aquifers and critical water supplies must be prevented; and (4) the strategy must recognize the wide variation across the

country in the nature, vulnerability, and use of groundwater and in states' and local governments' ability to manage it.

The Policy Forum recommended a new environmental partnership to avoid creation of a new and burdensome bureaucracy. Partners should include federal, state and local governments, private industry, and public interest groups. The Forum recommended that the partnership should be structured so that a clear national mandate is set forth while ensuring that states, assigned the lead role, have ample room to operate. Two key aspects from the states' perspective are to (1) consolidate groundwater laws and programs under the jurisdiction of a single state agency to facilitate a coordinated approach to problem prevention and solution and (2) provide substantial flexibility to design programs that respond to specific local needs. The federal government's role was envisioned as balancing national consistency with the reality of geographic differences. Ten components of a prototype state groundwater protection program were identified:

1. comprehensive mapping of aquifer systems and their associate recharge and discharge areas;
2. anticipatory classification of aquifers;
3. ambient groundwater standards;
4. authorities for imposing controls on all significant sources of potential contamination;
5. programs for monitoring, data collection, and data analysis;
6. effective enforcement provisions;
7. surface-use restrictions to protect groundwater quality;
8. programs to control groundwater withdrawals to protect groundwater quality;
9. coordination of groundwater and surface-water management; and
10. coordination of groundwater programs with other relevant natural resource protection programs.

Other institutional arrangements to implement the prototype program are discussed by the Conservation Foundation (1987).

Summary

The three major water-related environmental problems identified in this assessment--acid deposition, erosion, and groundwater contamination--all stem from externalities--resource management actions that fail to take full account of the potential disruption to ecosystems caused by pollutants. Pollutants are nothing more than resources out of place. When removed from their proper place, these resources cause ecosystems to change in ways not desirable to society as we know it. There are several steps to solving the problems created by resources out of place. The first is deciding how we want ecosystems to function. This step involves deciding how much ecological change society deems acceptable. "No change" is rarely a viable option, for resource use invariably changes ecosystems in one way or another. The second step is identifying the mechanisms by which unacceptable ecosystem changes are occurring. With erosion, this step has been answered more fully than for acid deposition or groundwater contamination. The third step is devising a way to alter the mechanisms causing unacceptable ecosystem changes. The tools to do so include

market-oriented processes and institutional processes, such as regulations or legislation. Today's society appears to prefer using market-forces instead of institutional processes. But if market pressures are demonstrated to be ineffective for technical (no efficient way to collect prices) or theoretical ("market-failure") reasons, society has no qualms about insisting on using institutional processes. Dickering over the ways, means, and costs via the political system is the way our society achieves consensus on attacking problems.

This section of Chapter 1 has focussed specifically on the second step in general process outlined above. The major causes of acid deposition, erosion, and groundwater contamination have been reviewed with the objective of describing the sources and scope of the problems. The abbreviated discussions of acid deposition, erosion, and groundwater contamination presented here are only abstracts of the highlights from the literature cited in this chapter. Interested readers should consult the literature cited as they contain a wealth of more detailed information on the subjects.

Condition and Distribution of the Nation's Wetlands

Present Distribution of Wetlands by Size and Region

There are currently 90 million acres of wetlands in the lower 48 states, about 5 percent of the total land area. Of this amount, 95 percent are inland freshwater wetlands and 5 percent are of the coastal saltwater type.

Wetland ecosystems are especially prevalent in Alaska. That state alone has approximately 200 million acres of wetlands (60 percent of its land area); over twice the total of the lower 48 states. Outside of Alaska, the largest concentrations of wetlands are found in the North and South. Those located in the South are primarily caused by sedimentation--soil is eroded from seacoasts or riverbanks and deposited behind burner islands or onto alluvial plains. Wetlands caused by glaciation are found in the North and scattered throughout the West. Glaciers form wetlands in three ways: large blocks of ice melt to form depressions; rivers are dammed by glacial debris; and lake beds are formed by scouring action. Other causes of wetlands are beaver dams, human activity, wide erosion, geologic movement, such as sinkholes, and freezing/thawing. Alaska's wetlands are caused by the last category--soils near one surface thaw on a seasonal basis but their moisture is prevented by permafrost from entering the water table. Wetlands are especially prevalent in the upper Midwest, the lower Mississippi River valley and along the Atlantic Ocean and Gulf of Mexico, figure 1.8 and table 1.7.

Throughout history, wetlands have been considered "wastelands" that could only be put to productive use if they were drained or filled. Within the last 200 years, over 50 percent of the wetlands in the lower 48 States have been converted to other uses, such as agriculture, mining, forestry, oil and gas production and urbanization. These losses are continuing today at an alarming rate--an estimated 350,000 to 500,000 acres annually.

Figure 1.8--Distribution of wetlands and their origins

Note: Shaded portions incorporate general wetland areas. Each dot represents about 10,000 acres.

SOURCE: Adapted from Samuel P. Shaw and C. Gordon Fredine, "Wetlands of the United States: Their Extent and Their Value to Waterfowl and Other Wildlife," Fish and Wildlife Service, U.S. Department of the Interior, Circular 39, 1956.

Table 1.7--Geographic distribution of wetlands, by type

Wetland type	Water resource region
Inland freshwater marsh	South Atlantic-Gulf Souris-Red-Rainy Texas-Gulf
Inland saline marsh	Lower Colorado Great Basin Pacific Northwest California
Bogs	South Atlantic-Gulf Great Lakes Ohio Upper Mississippi Lower Mississippi
Tundra	Alaska
Shrub and wooded swamps	South Atlantic-Gulf Great Lakes Ohio Upper Mississippi Lower Mississippi Texas-Gulf
Bottomland hardwoods	South Atlantic-Gulf Lower Mississippi Texas-Gulf
Coastal salt marshes	New England Mid-Atlantic South Atlantic-Gulf Texas-Gulf Pacific Northwest California
Mangrove swamps	South Atlantic-Gulf Texas-Gulf
Tidal freshwater wetlands	Mid-Atlantic South Atlantic-Gulf Texas-Gulf

Source: After Office of Technology Assessment (1984)

The most extensive inland wetlands losses have occurred in Louisiana, Mississippi, Arkansas, North Carolina, the Dakotas, Nebraska, Florida and Texas. Estuarine wetlands losses have been greatest in California, Florida, Louisiana, New Jersey and Texas.

The results of these wetlands losses have been devastating. In many coastal areas where estuarine wetlands losses are high, urbanization and increased ground-water withdrawals have resulted in saltwater contaminating public water supplies. In Chesapeake Bay--the largest estuary in the U.S.--sea grass and wild celery beds and tidal wetlands have been declining since the 1960s. In the upper Bay, they have almost disappeared. Canvasback ducks that thrived on the wild celery beds at the turn of the century are rarely found in the upper Bay anymore and their population in the lower Bay is down significantly.

In North Carolina, forestry and agriculture have played an important role in the loss of much of the evergreen forested and scrub-shrub wetlands known as **pocosins**. Most of this area has been transferred to large-scale agriculture. In addition to extensive land clearing and ditching, large quantities of fertilizers and lime must be added to these former wetlands to keep them fertile and productive. Runoff from these areas degrades the water quality of adjacent estuaries. In Environmental Protection Agency (1987), 12 States reported that wetlands were a special concern, figure 1.9.

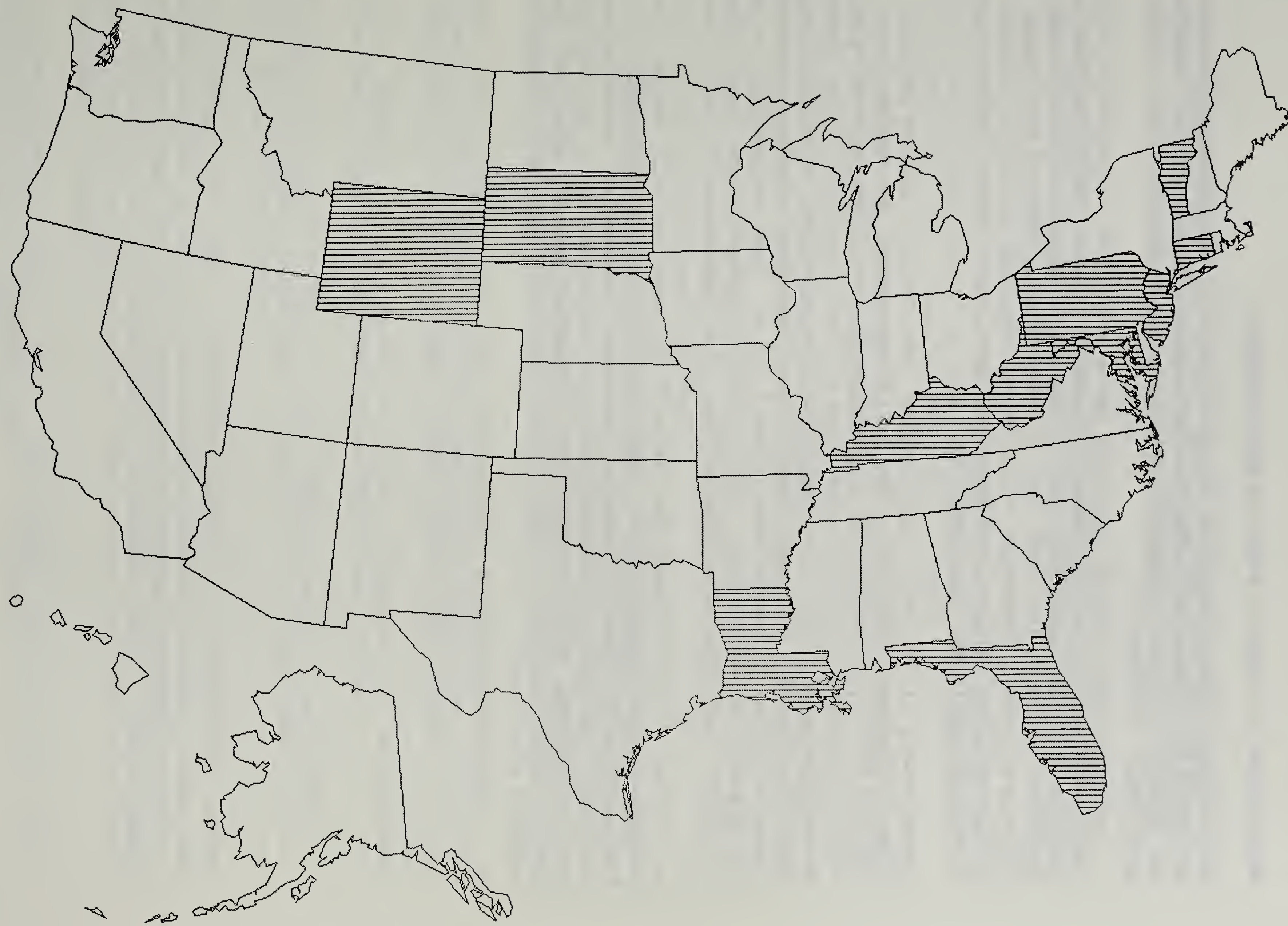
Influence of Wetlands on Reducing Peak Flow Rates

Wetlands provide an excellent way of controlling floodwaters because of their characteristics of gently sloping land and lush vegetation. Wetlands located on flood plains or in more isolated areas act like sponges soaking up excess flows thereby storing runoff and releasing the water gradually after the flood peak is past.

Influence of Wetlands on Maintaining Water Quality

Richardson (1988) concluded that wetlands are valuable from an ecological perspective because of their ability to transform, store, and recycle nutrients and sediments. By temporarily or permanently retaining pollutants, such as toxic chemicals, and disease-causing micro-organisms, wetlands can improve the quality of water that flows over and through them. Some pollutants that are trapped in wetlands may be converted by biochemical processes to less harmful forms. Some pollutants may remain buried; others may be taken up by wetland plants and either recycled within the wetland or transported from it. By temporarily delaying the release of nutrients until the fall when marsh vegetation dies back, wetlands can prevent excessive algal growth in open-water areas in the spring and summer. This habit has led some communities in coastal areas to move their wastewater effluent pipes from rivers and offshore areas to wetlands where marsh vegetation can remove the nutrients.

Figure 1.9--States reporting wetlands loss as a special concern



Regulations Influencing Wetlands Conversions

Section 404 of the Clean Water Act gives the U.S. Army Corps of Engineers the authority to issue permits for the discharge of dredged or fill material into the navigable waters at specified disposal sites. This program is discussed in more detail in Chapter 7.

Inland freshwater wetlands comprise 95 percent of the remaining wetlands resource in the U.S. and more than 90 percent of the estimated 300,000 of freshwater wetlands lost each year to development. Many of the losses involve drainage without a discharge, which is not regulated by the 404 Program. The 1985 Farm Bill should help mitigate this problem by discontinuing subsidies to farmers who drain and plant wetlands.

Approximately 11,000 permit applications under Section 404 are processed by the Corps of Engineers each year. The U.S. Environmental Protection Agency , the Fish and Wildlife Service, and the National Marine Fisheries Service all have a role in the permit review process. One of the roles of EPA is to determine if proposed use will have "an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas, wildlife, or recreational areas." If so, they can prohibit or restrict the proposed use of the site. After receiving comments from these agencies, the States, and other interested parties, the Corps makes its permit decisions.

As a result of this process, the Corps of Engineers annually denies about three percent of permit applications. About one-third of the permits are significantly modified from their original application, and about 14 percent of the permit applications submitted each year are withdrawn by the applicants. The Congressional Office of Technology Assessment has estimated that these denials, modifications, and application withdrawals save 50,000 acres of wetlands every year.

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Notes

1. The material in this section is drawn largely from Foxworthy and Moody (1986).

2. Precipitation variability is even more extreme than depicted in figure 1.3 because of gauging station locations. Gauging stations are typically located at or near settlements to facilitate daily reading of the instruments. In mountainous areas, settlements are nearly always situated in valley bottoms where precipitation is often much lower than on the slopes or tops of the nearby mountains.

3. See the discussion by Mark Reisner in Cadillac Desert, published by Viking-Penguin, Inc., New York, NY in 1986.

4. Organic Administration Act of June 4, 1897 (Ch. 2, 30 Stat. 11, as amended; 16 U.S.C. 475).

5. The information in this section is drawn largely from "Water Availability Issues" in Moody, D.W. and E.B. Chase (compilers). National Water Summary 1983. Reston, VA: U.S. Geological Survey. 1984. pp. 36-45.

6.The discussion is drawn largely from Foxworthy and Moody (1986).

7. Information in this section is drawn largely from three sources. Anon. (1984) provided an overview. Smith and others (1987) reports trends based upon information data from two stream sampling networks operated by the Geological Survey. U.S. Environmental Protection Agency (1987) is a draft of a biennial report to Congress.

8. The discussion that follows was drawn largely from U.S. Environmental Protection Agency, 1987).

9. Funding needs for waste treatment was also listed as a concern by 10 states. The funding concerns reflect expectations of additional funding cutbacks; because they have not yet occurred, the funding cutbacks were not analyzed in this report.

10. The discussion in this section is drawn largely from Council on Environmental Quality (1987), unless information is otherwise cited.

11. Alkalinity is a measure of the acid neutralizing capability of a waterbody. When a strong acid, such as sulfuric, enters the water, the natural alkalinity in the water buffers the acid added by chemically neutralizing it. In so doing, some of the alkalinity is consumed. So, a decline in alkalinity

shows that acid entered the waterbody but was neutralized.

12. T is a measure of the erosion potential of the soil and its associated vegetative cover. Its use to evaluate land condition is explained more fully in Department of Agriculture (1987).

13. Personal conversation with Wayne Swank, Forest Service Research Hydrologist, during the review of the water aspects of the South's Fourth Forest (U.S. Forest Service 1988).

14. Landowners can, however, lease the land for hunting. This is not deemed a commercial purpose according to the implementing regulations. So if vegetation is selected that favors game production, farmers can obtain a limited additional income from lands in the CRP during the first decade. As this report was being prepared in June 1988, some interests were advocating reopening these lands for grazing to provide forage during the pending drought.

Chapter 2

THE DEMAND SITUATION FOR WATER

Historical Overview of Demand for Water

The emergence and growth of the United States as an industrialized nation has been closely tied to the use of water. Settlement along the Atlantic Coast was initially tied to use of water for transportation--settlements quickly sprung up at good harbors. Commercial fishing and trade were early water-based stimulants to local economies. Inland waterways became transportation corridors for trade in both raw materials and finished goods. By the early 1800s, settlements were well-established at many of the locations where favorable conditions of flow and topography permitted waterpower to be harnessed for milling products, such as grain, logs, and wool. Development of the steam engine in the early 1800s suddenly freed industries from having to locate on stream banks to secure waterpower and the Industrial Revolution took off.

After being a constraint on growth for 200 years, water was much less so for the rest of the 19th century. Instead, fuel for the steam engine became the primary constraint. Wood and coal instead of waterpower fueled industrial expansion into the early 1900s. Also during this period, railroads rose to prominence as a method of transportation, making the country much less reliant on boats and barges and on navigable streams and harbors. Water for drinking and water for waste disposal--these were the two uses of water that increased most rapidly to the beginning of the 20th century.

By the beginning of the 20th century, civilization had tainted most coastal waters and many inland streams. The rapid population growth of cities and the increasing concentrations of industry combined to overtax the ability of the Nation's water resources to meet all needs. Typhoid epidemics erupted in a number of cities along the East Coast around the turn of the century. The cause was finally determined to be contaminated drinking water. Chlorination had not yet been discovered. Rural and urban developments in the floodplain of major streams, such as the Mississippi, Missouri, and Ohio Rivers, both contributed to the cause of flooding as well as incurred damages due to flooding. Flood control structures--dams and levees--were fragmentary. In the Midwest and West, many areas could not sustain settlement because insufficient water was available for crops or animal husbandry. Securing the coal and wood needed to fuel the economic engine of the U.S. led to resource extraction practices that fouled waters with sediment and acid. Land reclamation and forest regeneration practices had not yet been developed.

By the middle of the 20th century, the country had begun to remedy many of these water and related land resource problems. Local, state, and federal agencies led the assault on the problems. Structural approaches to solving water resource problems were favored. The Army Corps of Engineers improved navigation and controlled flooding with locks, dams, dredging, levees, and other works. The Bureau of Reclamation built dams and irrigation structures to water the West. The Forest Service and SCS developed and installed land management practices to keep soil in place, thereby preserving clean water. The Tennessee Valley Authority began economic redevelopment of the southern Appalachians--a massive demonstration of how water resources could be better harnessed for economic development. Local and state governments installed water and waste treatment facilities to render potable supplies safe and remove suspended solids from wasteflows.

The demands for water today stem largely from this history of water developments. The inertia set in motion to drive economic development using water resources and structural developments of those resources continues to affect demand for water today and will for years to come. The trends in water withdrawals and consumption through the 1960s and 1970s show an inexorable climb in total use, marching lockstep with increases in gross national product (GNP) and population, respectively, figure 2.1.

But by the early 1970s, it became clear that while prior developments had, to a great extent, solved problems of water flow volumes, much remained to be done about problems of water quality. Public Law 92-500 and subsequent amendments and related water quality legislation provided the added momentum needed to preserve pristine water quality where it existed and to clean up fouled water to fishable and swimmable levels. The legislation provided a major shift in the long-run trend of ever-increasing withdrawals and consumption. The added cost of waste treatment imposed by the legislation made water conservation and recycling much more cost-effective than it had been in the past. Recent water withdrawals and consumption information (Solley 1987) has shown that the water quality legislation has also had a significant effect in retarding the growth in demand for withdrawals and consumption, figure 2.1.

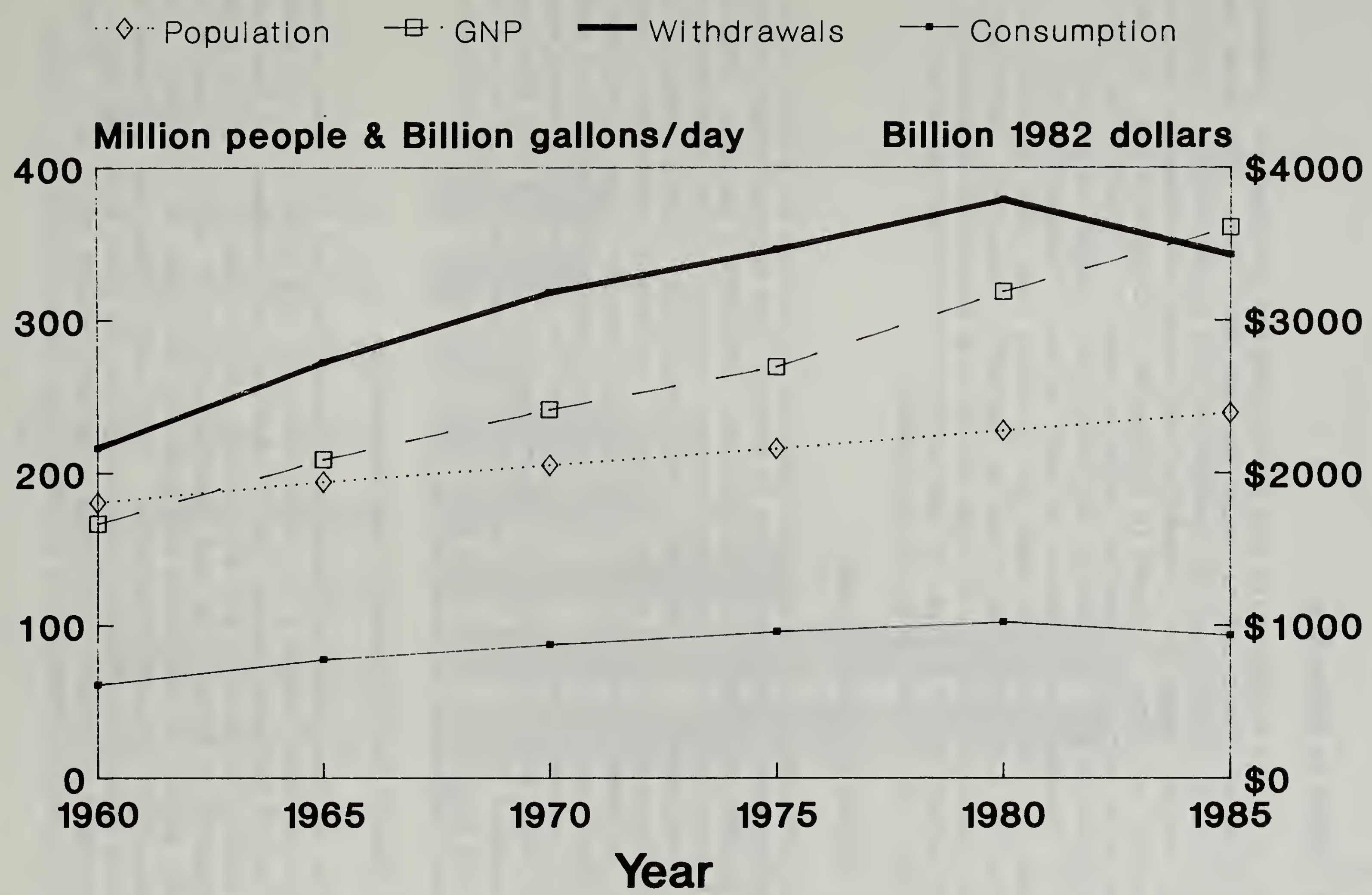
The purpose of this chapter is to review historical trends in the demand for water and to project those trends into the future. We begin by summarizing historical data on water withdrawals and consumption from USGS (MacKichan and Kammerer 1961, Murray 1968, Murray and Reeves 1972 and 1977, Solley, Chase, and Mann 1983, and Solley 1987). Projections of withdrawals and consumption are presented for the years 2000 to 2040 based on the USGS data from 1960 to 1985. Then, we review water demand projections made in other studies published since 1960. Comparisons of data recently collected with previous projections are then made.

Historical Data on Water Withdrawals and Consumption

National trends in Withdrawals and Consumption

The USGS has reported estimates of water use in the United States at five-year intervals since 1950 (MacKinchan 1951). The most recent data available is a

Figure 2.1--Rates of increase in GNP, population, and water withdrawals, 1960 to 1985



SOURCE: GNP and population increases from Dept. of Commerce publications. Withdrawals from U.S.G.S. Circulars

preliminary set for the year 1985 (Solley 1987). Withdrawals in 1960 totaled 216 bgd and consumption was 61 bgd.[1] By 1985, withdrawals totaled 343 bgd and consumption 93 bgd--increases of 59 percent and 52 percent, respectively, figure 2.2.

National Trends by Water Use

Increases in total withdrawals and total consumption obscure interesting trends in the six major categories of water use and over time. The water uses examined in this report include thermoelectric steam cooling, irrigation, municipal central supplies, industrial self-supplies, domestic self-supplies, and livestock watering. Trends in freshwater withdrawals vary by use. Withdrawals for municipal central supplies rose 79 percent from 1960 to 1985 while withdrawals for industrial self-supplies dropped 26 percent, table 2-1. Consumption trends also vary by use. Consumption by thermoelectric steam cooling rose 2063 percent from 1960 to 1985 while consumption by irrigation only rose 41 percent, table 2-2. Detailed tables of withdrawals and consumption by type of use are presented in Appendix A. Detailed discussion of trends by use category are presented later in this chapter when the projections are discussed.

National Trends by Water Source

Withdrawal and consumption trends also vary by source of water. From 1960 to 1985, groundwater withdrawals rose 78 percent and surface water withdrawals rose 53 percent but wastewater withdrawals declined 6 percent. The latter figure is particularly noteworthy because in early 1970s, wastewater reuse was strongly encouraged. The reduction apparently only counts water withdrawn from conveyance structures after municipal wastewater treatment. One of the policies implemented by regulations arising from the Clean Water Act was to charge industries the full cost of treating industrial wasteflows sent to municipal treatment plants. It now appears that industrial users adopted internal recycling strategies to reduce their waste flows and thus municipal waste treatment fees. The data showing industrial self-supplied withdrawals dropping 26 percent and consumption rising 85 percent are consistent with significant increases in internal recycling.

Regional Trends in Withdrawals and Consumption

The trends in freshwater withdrawals between 1960 and 1985 also varied among geographic regions, table 2.3. Withdrawals in the South and Rocky Mountains rose 85 and 75 percent, respectively--double the increases in the North and Pacific Coast, 42 percent and 37 percent, respectively. Over this period of time, Censuses of Population and Manufacturing both reported population and industrial growth in the South and West and declines in the North. Water withdrawals were similarly affected. The lower percentage increase in withdrawals along the Pacific Coast reflects the fact that the major increases in population and industry occurred in a water-short area (e.g. in Southern California) relying heavily on imports from other hydrologic basins.

Figure 2.2--Increases in withdrawals, consumption, and related variables from 1960 to 1985

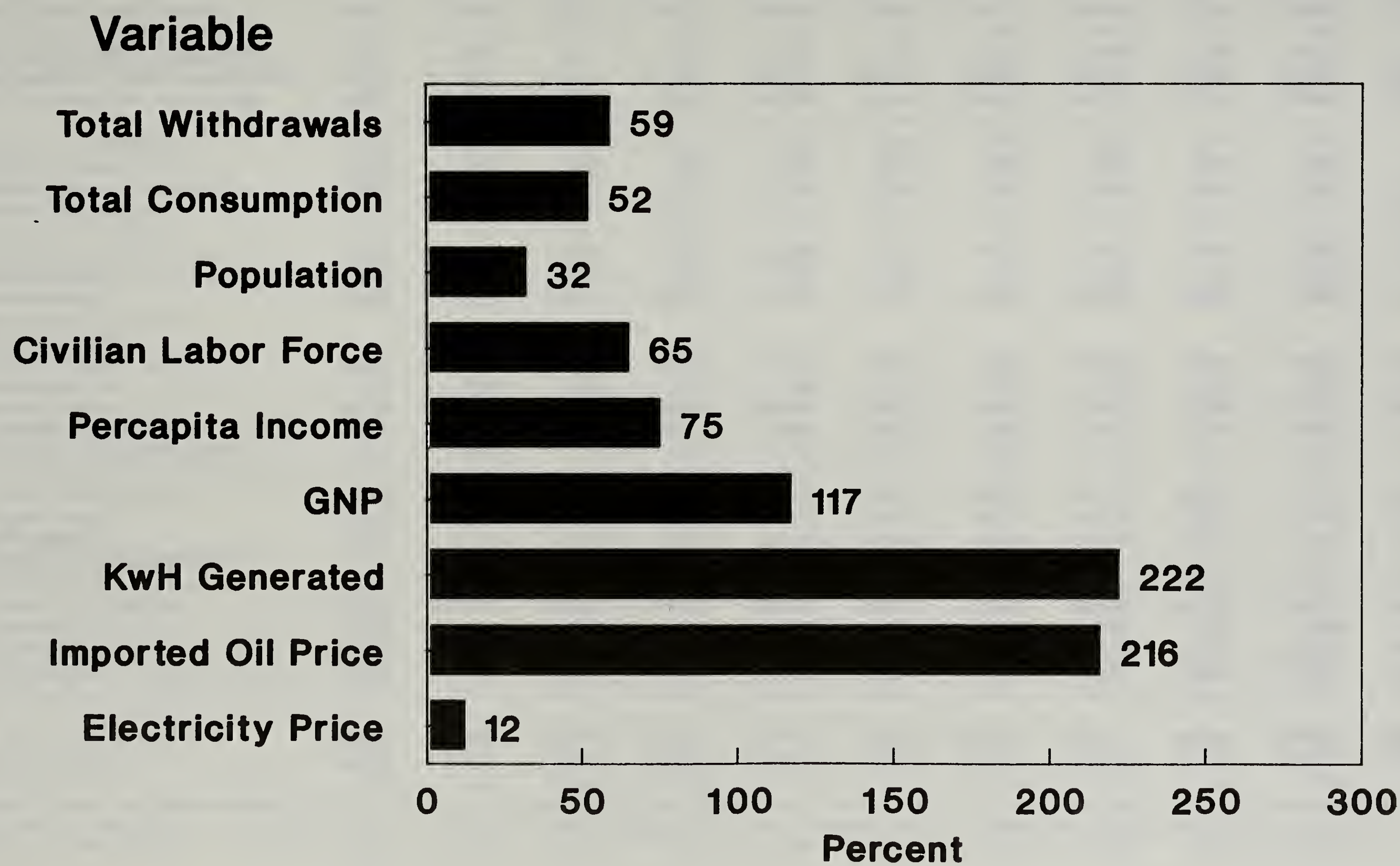


Table 2.1--Total freshwater withdrawals in the United States for 1960 to 1985, by water use and source, with projections of demand to 2040 (million gallons per day)

Water use and source	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Thermoelectric steam cooling											
Groundwater	920	1100	1400	1400	1600	630	700	700	690	680	680
Surface water	73100	90500	118300	129600	146800	130200	156700	174500	192200	209900	227600
Total Thermoelectric	74000	91600	119800	131000	148400	130800	157400	175200	192900	210600	228300
Irrigation											
Groundwater	30400	41600	45250	57100	61200	56300	55600	58300	60900	62650	64200
Surface water	54000	74400	81700	85000	90400	85800	86600	92900	99100	104210	109100
Wastewater	560	500	370	370	280	450	290	260	200	200	200
Total Irrigation	84900	116500	127300	142500	151900	142500	142500	151500	160200	167100	173400
Municipal central supplies											
Groundwater	6300	8100	9500	10800	11700	14900	20100	24100	28200	31600	33700
Surface water	14200	15700	17900	18800	22300	21800	30500	34600	38500	41640	43500
Total Municipal	20500	23800	27400	29600	34000	36700	50600	58700	66700	72300	77100
Industrial self-supplies											
Groundwater	6000	6800	8000	9700	10300	4650	5600	6400	7340	8310	9340
Surface water	27200	29700	31200	28600	28700	19810	21700	23600	25420	27220	28960
Wastewater	70	140	150	170	190	140	300	400	420	470	500
Total Industrial	33300	36600	39300	38500	39200	24600	27600	30400	33200	36000	38800
Domestic self-supplies											
Groundwater	1840	2200	2500	2670	3260	3250	4300	4800	5250	5600	5800
Surface water	160	120	120	130	180	80	80	60	40	30	30
Total Domestic	2000	2320	2620	2800	3340	3330	4380	4860	5290	5630	5830
Livestock watering											
Groundwater	825	1000	1070	1250	1200	2930	1500	1600	1690	1750	1780
Surface water	675	740	800	900	970	2100	1180	1260	1330	1380	1410
Total Livestock	1500	1740	1870	2150	2170	5040	2680	2860	3020	3130	3190
Total groundwater withdrawal	46285	60800	67720	82920	89260	82660	87800	95900	104070	110590	115500
Total surface water withdrawal	169335	211160	250020	263030	289350	259790	296760	326920	356590	384380	410600
Total wastewater withdrawal	630	640	520	540	470	590	590	660	620	670	700
U.S. Total Withdrawals	216200	272400	318300	346600	379000	343000	385200	423600	461300	494800	526600

NOTE--The sum of totals by use and by water source differ because of independent rounding of intermediate sums.

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table 2.2--Total freshwater consumption in the United States for 1960 to 1985, by geographic area and use, with projections of consumption to 2040 (million gallons per day)

Water use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
North											
Domestic self-supplies	427	517	513	356	594	458	482	494	504	511	515
Industrial self-supplies	1045	1351	1187	1177	1247	2282	2790	3155	3523	3891	4262
Irrigation	233	398	460	613	1278	1187	1417	1481	1543	1592	1637
Livestock watering	603	628	614	689	623	633	643	680	711	733	746
Municipal central supplies	1329	1735	1881	1749	1615	1399	2335	2575	2783	2931	3016
Thermoelectric steam cooling	53	87	106	630	1294	3406	5457	6539	7379	8483	9829
Total North	3691	4717	4762	5215	6651	9366	13124	14924	16443	18142	20005
South											
Domestic self-supplies	519	798	721	661	842	696	732	750	766	777	783
Industrial self-supplies	1524	1581	2220	2075	2781	1945	2378	2690	3003	3317	3633
Irrigation	9143	14913	12646	17564	16356	14699	17550	18349	19116	19717	20278
Livestock watering	416	472	540	680	769	911	925	977	1022	1054	1073
Municipal central supplies	1139	1301	1612	2323	2172	1882	3140	3464	3742	3942	4056
Thermoelectric steam cooling	96	228	568	1061	1536	1085	1739	2083	2351	2703	3132
Total South	12837	19294	18307	24364	24455	21218	26464	28312	29999	31509	32954
Rocky Mountains											
Domestic self-supplies	120	136	161	188	293	201	211	216	221	224	226
Industrial self-supplies	157	248	378	601	625	411	503	569	635	701	768
Irrigation	24073	30491	34755	34999	36242	31689	37836	39558	41212	42508	43717
Livestock watering	315	439	476	498	430	525	533	563	589	607	618
Municipal central supplies	495	584	756	857	1303	1129	1883	2077	2244	2364	2432
Thermoelectric steam cooling	48	83	126	207	369	301	482	578	652	750	869
Total Rocky Mountains	25208	31981	36651	37350	39260	34255	41449	43561	45553	47154	48631
Pacific Coast											
Domestic self-supplies	151	117	261	244	253	237	249	255	261	264	267
Industrial self-supplies	249	181	306	332	364	854	1044	1180	1318	1456	1594
Irrigation	18576	20095	25608	26745	29243	25707	30695	32091	33433	34484	35465
Livestock watering	103	82	82	84	80	207	211	223	233	240	244
Municipal central supplies	508	1517	1675	1737	2006	1739	2901	3199	3457	3641	3746
Thermoelectric steam cooling	27	18	24	40	42	54	86	103	117	134	155
Total Pacific Coast	19614	22010	27957	29182	31987	28798	35185	37052	38817	40220	41472
U.S. Total Consumption	61350	78002	87677	96111	102353	93636	116222	123850	130812	137025	143062

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table 2.3--Total freshwater withdrawals in the United States from 1960 to 1985, by geographic area and water source, projections of demand to 2040 (million gallons per day)

Region and water source	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
North											
Groundwater	5625	7130	8750	8920	9930	10010	12060	13840	15670	17225	18365
Surface water	70735	92000	107355	106975	110050	96290	117110	130450	143600	156350	168450
Wastewater	80	125	130	155	190	105	250	310	325	375	415
Total North	76440	99255	116235	116050	120170	106405	129420	144600	159595	173950	187230
South											
Groundwater	15570	21820	19165	23650	24040	24150	25795	28280	30790	32830	34390
Surface water	34635	42765	57415	68265	83295	68995	82360	91450	100400	109050	117300
Wastewater	30	5	20	65	70	170	100	110	100	105	105
Total South	50235	64590	76600	91980	107405	93315	108255	119840	131290	141985	151795
Rocky Mountains											
Groundwater	12690	15920	18675	27920	31140	27780	27515	29220	30890	32125	33120
Surface water	36420	47420	52740	53380	59745	59300	61475	66320	71075	75100	78850
Wastewater	90	125	170	155	35	55	70	75	65	60	60
Total Rocky Mountains	49200	63465	71585	81454	90920	87135	89060	95615	102030	107285	112030
Pacific Coast											
Groundwater	13400	15930	21130	22430	24150	20720	22430	24560	26720	28410	29625
Surface water	27545	28975	32510	34410	36260	35205	35815	38700	41525	43880	46000
Wastewater	430	385	200	170	175	260	165	165	135	130	120
Total Pacific Coast	41375	45290	53840	57010	60585	56185	58410	63425	68380	72420	75745
Total groundwater	46285	60800	67720	82920	89260	82660	87800	95900	104070	110590	115500
Total surface water	169335	211160	250020	263030	289350	259790	296760	326920	356590	384380	410600
Total wastewater	630	640	520	540	470	590	590	660	620	670	700
U.S. Total Withdrawals	216200	272400	318300	346600	379000	343000	385200	423600	461300	494800	526600

NOTE--The sum of totals by region and by water source differ because of independent rounding of intermediate sums.

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Consumption trends by region show a different story. Consumption in the North increased 154 percent, far eclipsing the increases in the South (65 percent), Pacific Coast (47 percent) and Rocky Mountains (36 percent). Because the North is more heavily industrialized than the other parts of the United States, it shows a larger increase in consumption than the other regions. Irrigation is the primary component of consumption in the other three regions. There have been smaller percentage increases in consumption in irrigation than in the industrial sector.

Projected Demands for Water

The projections from 2000 to 2040 presented here are the result of Forest Service analyses conducted especially for this Assessment. The projections are not the Forest Service interpretation of a "most likely" scenario. The projections are a statement of the demand levels in 2040 if recent trends in demand for water continue. The projections of withdrawals and consumption are intended to suggest what future demands will be if water resource management continues as it has from 1960 to 1987. But some of the demand projections lead to environmental, social and economic implications at odds with the Nation's goals. Consequently, we view these demand projections as a description of the "without" condition; the basis for evaluating the impacts of possible changes in water resource management to better achieve the Nation's environmental, social and economic goals for the future.

In the course of analyzing the demand data, it became clear that simple linear extrapolation of the data from 1960 to 1985 did not fit the data as well as semi-logarithmic or logarithmic curve forms. Linear trends usually had the 1985 datum well beneath the trend line and the 1980 datum on or slightly beneath the line. The Water Resources Council (1978) projected that the **rate of increase in demand** from most uses would decline drastically by the year 2000 as a consequence of Clean Water Act. They believed that water conservation and internal recycling would combine to hold demands in the year 2000 at about 90 percent of the 1975 level. The 1980 data were close enough to the 1975 data that one could not be certain whether the rate of increase in demand had begun to decline already or if the 1980 data were but a momentary pause in the rate of increase. The 1985 data provide conclusive evidence that demand has been strongly affected by the legislation and regulations of the 1970s--in fact, there was about a decade's lag between changing national policy and the effects of the policy change becoming apparent. Because structural changes in waste treatment and water conservation required planning, design, and securing of funding after regulations were written and before construction could begin, a ten-year lag between the passage of the law and the first clear evidence of changes in water use is reasonable.

Semi-logarithmic and logarithmic curve forms provided a better fit to the historical data than the linear trends. The curves imply that conservation and recycling will continue to occur at levels mandated by 1970s legislation. Additional increments of waste treatment and recycling beyond that mandated by existing legislation are not assumed to occur in the future. Comparisons of projections in 2040 between linear and the two curve forms showed that, on average, demands are 15 to 20 percent lower for the curve forms than the linear

form. The analyses suggest that is a reasonable expected gain from conservation and recycling.

The 1987 release of BMDP Statistical Software (Dixon and others 1985) for personal computers was used to analyze the data and perform the projections. Standard BMDP diagnostics were used to evaluate statistical fit and significance. The projection equations and goodness-of-fit statistics are listed in Appendix B. The data consisted of historical water withdrawal and consumption information from the Geological Survey reports and demographic information forming the basic assumptions for this Assessment, table 2.4.

Projections were made by water use category at the national level. The projections were then disaggregated to water resource regions and Forest Service Regions based upon the shares each region had of the 1985 total withdrawals and consumption. Where the historical data suggested that the regional shares were changing, a continuation of the rate of change was factored into the disaggregation process. The results are displayed in tables 2.1-3 and in Appendix A.

Thermoelectric Steam Cooling

Description of the Use--Thermoelectric power is electricity generated using either fossil-fuel (coal, oil, or natural gas), renewable (wood or geothermal), or nuclear energy. No matter what the energy source, the principal method of generating electricity is to convert water into steam and then use steam pressure to propel the generator's turbine. Spent steam recondenses into hot water which must then be dealt with in some way. In nuclear reactors, the steam generation and recondensation process is typically a closed-loop process where the recondensed water is recycled back to the boiler. Cooling water is used to assist the recondensation process. In fossil-fuel and geothermal power plants, the process is not always a closed loop. "Once-through" cooling was the norm until the early 1970s. Legislation then recognized that putting excess heat back into the aquatic environment was as damaging as putting excess nutrients or allowing suspended sediments into the streams. Excess heat is called **thermal pollution**. Today, power generation facilities use a variety of ways to get rid of waste heat to the atmosphere before piping the cooling water back to the stream. Some plants use cooling towers or cooling ponds, relying upon evaporation to cool the water. These are often effective enough that the cooled water can be recycled through the plant again. As recycling increases, the amount of water consumed through evaporation will increase.

Electricity generation in the United States has set a new record every year since the early 1940s, except for 1982. In 1985, a new record was set of 2.47 trillion kiloWatt-hours (kWh). Electricity generation from petroleum, natural, gas, and hydroelectric power has continued to decline, while generation using coal, nuclear, and renewable resources has continued to rise, figure 2.3 (Energy Information Administration 1986a). These changes continue the shifts in mix of fossil fuels that have been underway since the 1950s. The share of electricity generated by natural gas and petroleum has fallen from 37 percent in 1972 to only 16 percent in 1985. Generation using petroleum products peaked at 365 billion kWh in 1978 and declined to 100 billion kWh in 1985. Generation using natural gas peaked at 376 billion kWh in 1973 and has dropped to

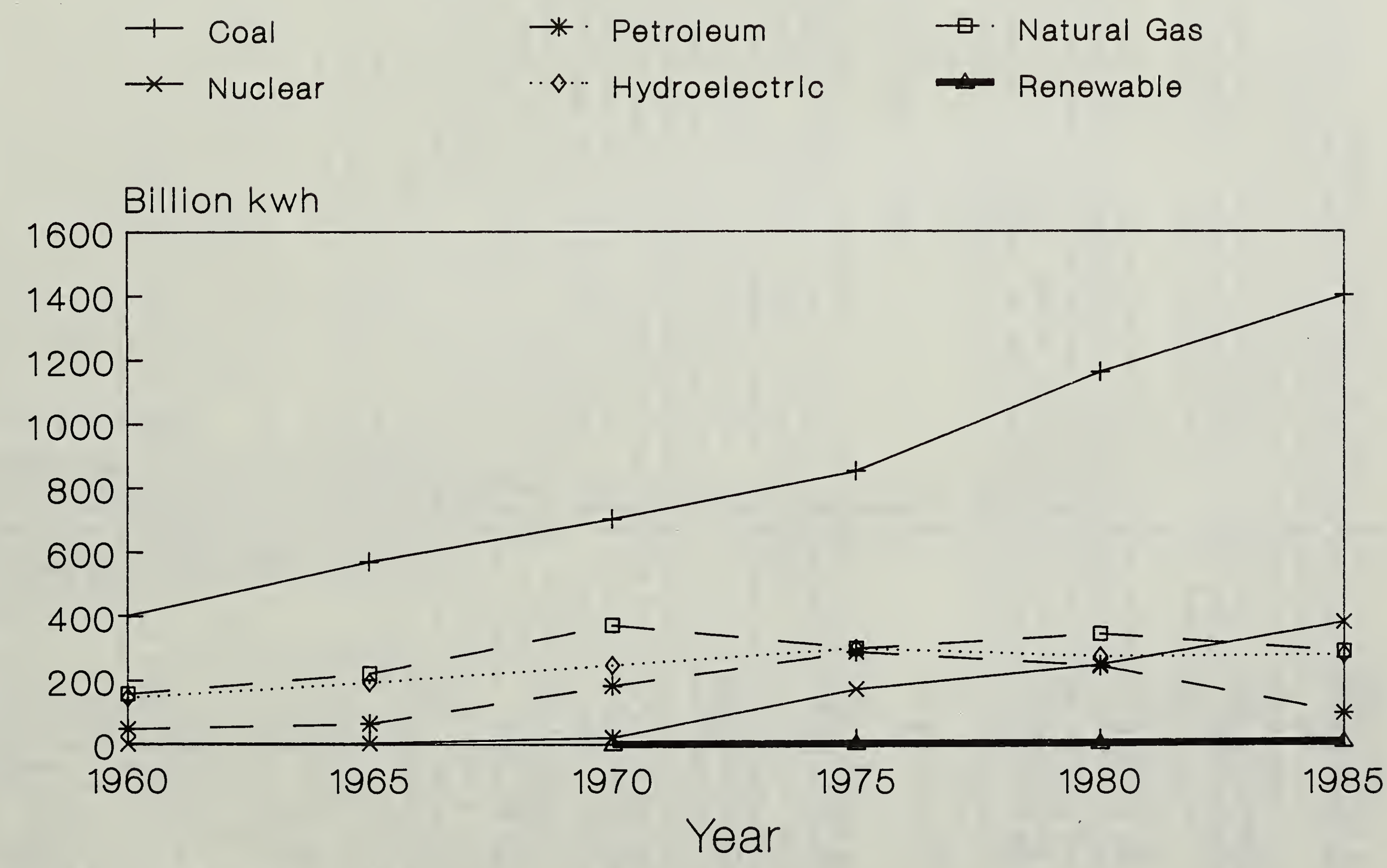
Table 2.4--Data used to project withdrawals and consumption

Variable	1955	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Population[1]	165.9	180.7	194.3	205.1	216.0	227.8	239.3	274.9	294.3	312.1	325.5	333.4
Civilian labor force[2]	65.02	69.63	74.45	82.77	93.77	106.94	115.46	142.54	159.16	175.09	192.26	211.86
Disposable income[3]	5.71	6.06	7.03	8.13	8.94	9.72	10.62	13.92	16.73	19.66	23.53	28.79
Gross national product[4]	1494.9	1665.3	2087.6	2416.2	2695.0	3187.1	3607.5	5402.0	7031.3	9166.1	11956.7	15626.0
Billion kwh generated[5]	-----	557.	791.	1143.	1318.	1612.	1794.	2311.	2765.	3285.	3760.	4265.
Imported oil price[6]	-----	7.67	7.35	7.05	23.49	39.54	24.21	32.08	51.10	69.85	88.86	107.88
Electricity price[7]	-----	16.10	14.20	12.50	15.00	17.50	18.00	19.00	19.50	20.00	20.50	21.00

1 Million people
2 Million people
3 Thousand 1982 constant dollars per capita
4 Billion 1982 constant dollars
5 Generation by fossil-fueled powerplants. Historical information from Energy Information Administration, projections based upon the historical linkage between GNP and electricity demand described in Department of Energy documents.
6 Constant 1982 dollars per barrel, F.O.B. domestic refinery.
7 Constant 1984 dollars per million BTUs

Source: Darr (1987)

Figure 2.3--Changes in net generation of electricity by fuel source, 1970-1985



SOURCE: Energy Information Administration (1986)

292 billion kWh since then. The share generated by coal and nuclear fuel has risen over the same time period from 47 percent to 72 percent. Generation using coal has increased more than 100 percent since 1970 and stood at 1,401 billion kWh in 1985. Nuclear power generated 384 billion kWh in 1985, a 1000 percent increase since 1971. The share of electricity generated by hydropower is also on the decline. Although outputs have remained essentially constant, subject to vagaries of the weather, the share has fallen because total generation has increased. Hydroelectric power peaked at 332 billion kWh in 1982, but dry weather in recent years resulted in a decline to 282 billion kWh in 1985.

Choice of fuels varies across regions due to availability and transportation costs. The Northeast relies primarily upon nuclear and oil-fired units; the Pacific Coast on natural gas and hydropower. All other regions—especially those in the South and Southwest experiencing the largest rates of population and industrial growth—depend primarily upon coal (Energy Information Administration 1986b).

A recent examination of electricity demand between 1953 and 1983 determined that a structural change did occur in 1973 following the Arab oil embargo (Energy Information Administration 1985). A more recent study (Cornett 1985) has analyzed changes in demand in the early 1980s following the structural change. This analysis demonstrated that changes in demand were uneven across sectors of the economy and areas of the country. Less rapid growth in electricity use in the residential and commercial sectors can be explained mainly by conservation measures in response to higher electricity prices. Average growth of about 2.0 percent per year in residential electricity demand between 1980 and 1984 compares with average annual GNP growth of 2.7 percent for the same period. Average growth in commercial demand exceeded 4 percent. Industrial growth in electricity demand was down sharply during the last recession. Average annual growth in demand was only 0.8 percent per year—less than one-third the growth rate in GNP. If growth in residential and commercial demand for electricity remains moderate (as a result of slow growth in housing and commercial sectors) and growth in industrial output remains low, then the ratio of electricity-to-GNP growth rates could remain below 1.0—barely half of the 1.8 average ratio for the 1953-1984 period. Cornett (1985) found that most of the change in residential and commercial demand for electricity in the early 1980s can be attributed to changes in real income. The change in industrial demand for electricity is attributed largely to changes in output associated with the recession. Cornett concluded that if recent sluggish output trends in the housing construction, food, paper, chemicals, and primary metals sectors (the four biggest industrial users of electricity) continue, and if gains in energy efficiency continue because prices remain high, then future electricity/GNP growth ratios will continue to remain below 1.0.

Cornett's outlook for electricity demand was amplified in the National Energy Policy Plan (Department of Energy 1985). Energy productivity (GNP per unit of energy consumed) rose 28 percent between 1974 and 1985—14 percent between 1981 and 1985, the greatest improvement in efficiency since World War II. This progress is continuing for all types of energy, including electricity use. Energy conservation has made a bigger contribution to reducing the need for new or imported energy resources than any switching in fuels has accomplished (e.g.

substituting coal for petroleum). The plan proclaimed coal as the fuel for America's future. It has become the main fuel for electric utilities--modern coal-fired powerplants are cleaner than most older oil-fired plants. New technologies to burn coal are being developed that promise even higher efficiencies and environmental performance. The increased demand for coal will lead to more mining, which has implications for mine-related water impacts.

Nuclear energy is now the second-largest source of electricity, providing 15 percent of the Nation's needs. That percentage is expected to rise to 20 percent by the turn of the century. Renewable energy resources--now primarily wood and water--contribute about 9 percent of the country's domestic energy production. This percentage could rise to nearly 13 percent by the end of the century and to 15 percent by 2010 as more economical renewable energy technologies (e.g. wood, geothermal, solar, or wind) develop.

Future trends in energy consumption, and particularly electricity consumption, suggest that the efficiency increases will continue. The National Energy Policy Plan projects that it could take 20 to 30 years to gain full advantage of all the opportunities for efficiency that have been recognized in the industrial sector. The residential sector has shown a 40 percent drop in energy use per household since 1973--due largely to improved insulation, improved appliance efficiency, and changes in household behavior. Further, the average efficiency increase in energy-using capital goods will increase over time by an additional 20 to 50 percent as the stock continues its normal turnover and more efficient technologies are implemented gradually.

Given the assumptions of energy conservation outlined above, the nation will need between 100 and 300 gigawatts of new electrical generation capacity between now and the year 2000, over and above the 70 gigawatts already under construction in late 1985. This new capacity will be needed to replace obsolete units as well as satisfy growth in electricity demand. The nation currently has some excess electrical generation capacity. Utilities are trying to stretch their capacity by improving operation and maintenance. They hope to boost the utilization factors of generating units by 10 to 25 percent. This more intensive use of existing capital will help postpone new construction, but does not significantly reduce cooling water needs. Another way of meeting power demands is to import energy. Power imports from Canada (principally hydropower) have grown six-fold since 1970. They are expected to double from the current 40 billion kWh level (2 percent of domestic demand) to 80 billion kWh by the year 2000 (3 percent of domestic demand). Between the excess capacity and improving utilization, conservation, interconnection of power distribution networks, and imports from Canada, public utilities are attempting to stave off the need for construction of new powerplants.[2] However, by the turn of the century, significant expansions in the construction programs of many utilities will inevitably occur to meet rising demand.

Current projections by the Department of Energy show demand for electricity growing in rough proportion to the growth in the nation's economy for the foreseeable future. The question pertinent to this Assessment is the nature of the relationship, because cooling water withdrawals are made in direct proportion to the number of kWh generated by fossil-fuel, nuclear, and wood-burning powerplants. All the conclusions by the Department of Energy (1985)

suggest that the historic tie between the rate of growth in GNP and electricity demand has undergone a major structural change since the mid-1970s and that the ratio of growth in electricity generated to growth in GNP is likely to stay below 1.0 well into the next century. The efficiency gains reported and expected mean that the Nation will use less electricity to produce increments of GNP in the future than in 1950s and 1960s. Consequently, this Assessment adopts the 0.8 ratio determined by the Department of Energy for the early 1980s and projects kWh as a linear function of the growth in GNP.

Magnitude of Water Use and Trends--Thermoelectric powerplants furnish practically all of their own water; less than 1 percent is obtained from public supplies. In 1985, total water withdrawals for thermoelectric steam cooling totaled 187 bgd--a decrease of 11 percent from 1980. This total includes 131 bgd of freshwater and 56 bgd of saline water (saline water withdrawals and consumption are not studied in this Assessment). The 1985 freshwater withdrawal level is 12 percent less than the 1980 level and the same as withdrawals in 1975--even though the kWh generated have increased 36 percent since then (figures 2.4-2.7; tables A.1, A.7, and A.13; figures A.3 and A.4).

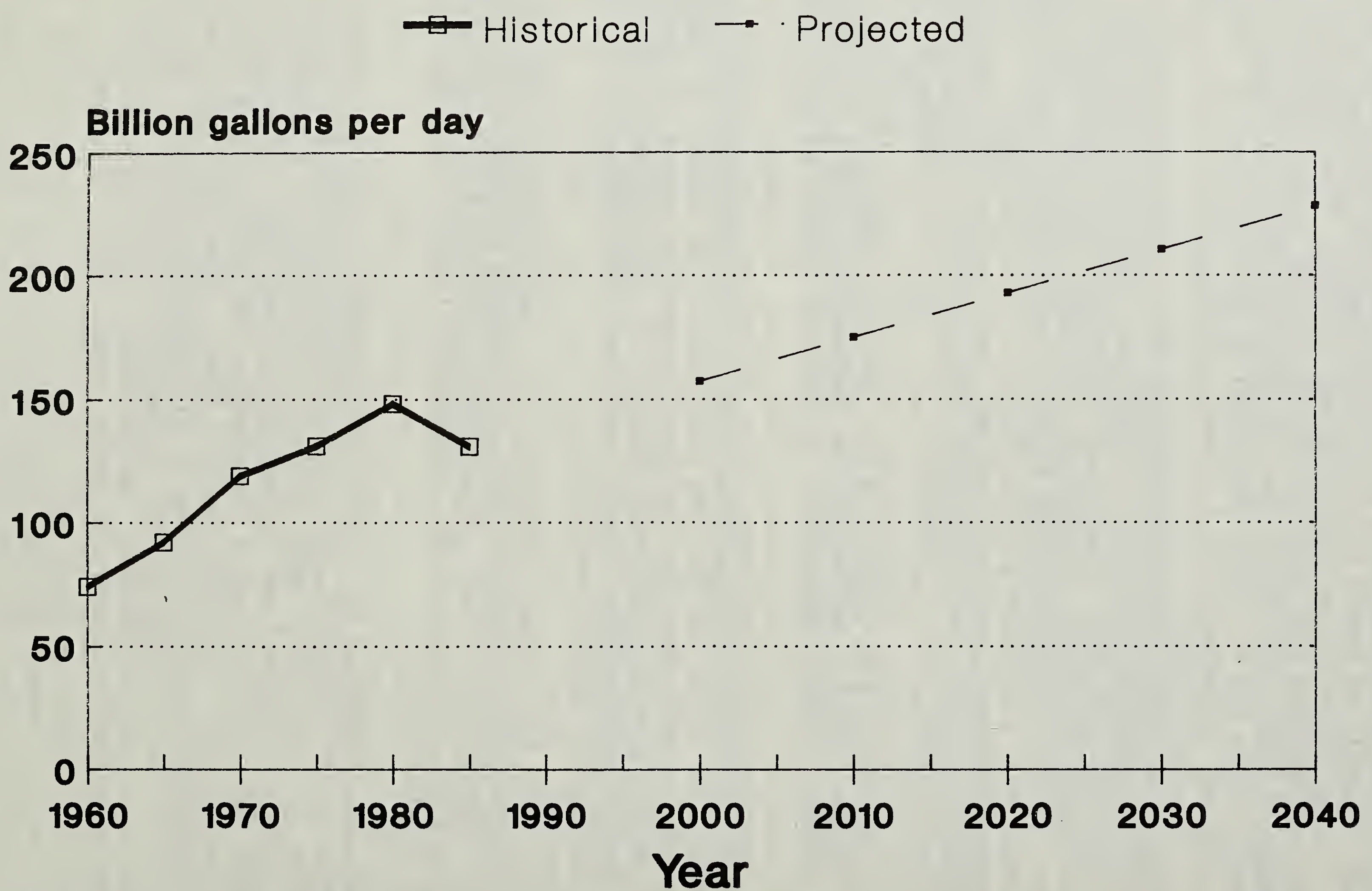
About 99 percent of the withdrawals are used for condenser and reactor cooling of generators. About 4 percent of the freshwater withdrawn is consumed, up from 2 percent in 1980, one percent in 1975 and one-half of one percent in 1970.

Thermoelectric steam cooling is the second largest withdrawal use next to irrigation. It is the use that has been growing the fastest in recent years. The assumptions made about the continued increase in demand for electricity lead to projections of withdrawals that make it the largest use of water by 2040. Most of the increase in water use comes after 2000 when a large number of new powerplants begin generation.

Although one of the largest withdrawal uses, thermoelectric steam cooling is one of the smallest consumptive uses. Consumption has been rising rapidly, but from an extremely small base. Consumption is projected to double by 2010 and triple by 2040. But even by 2040, consumption is still projected to be only 6 percent of withdrawals.

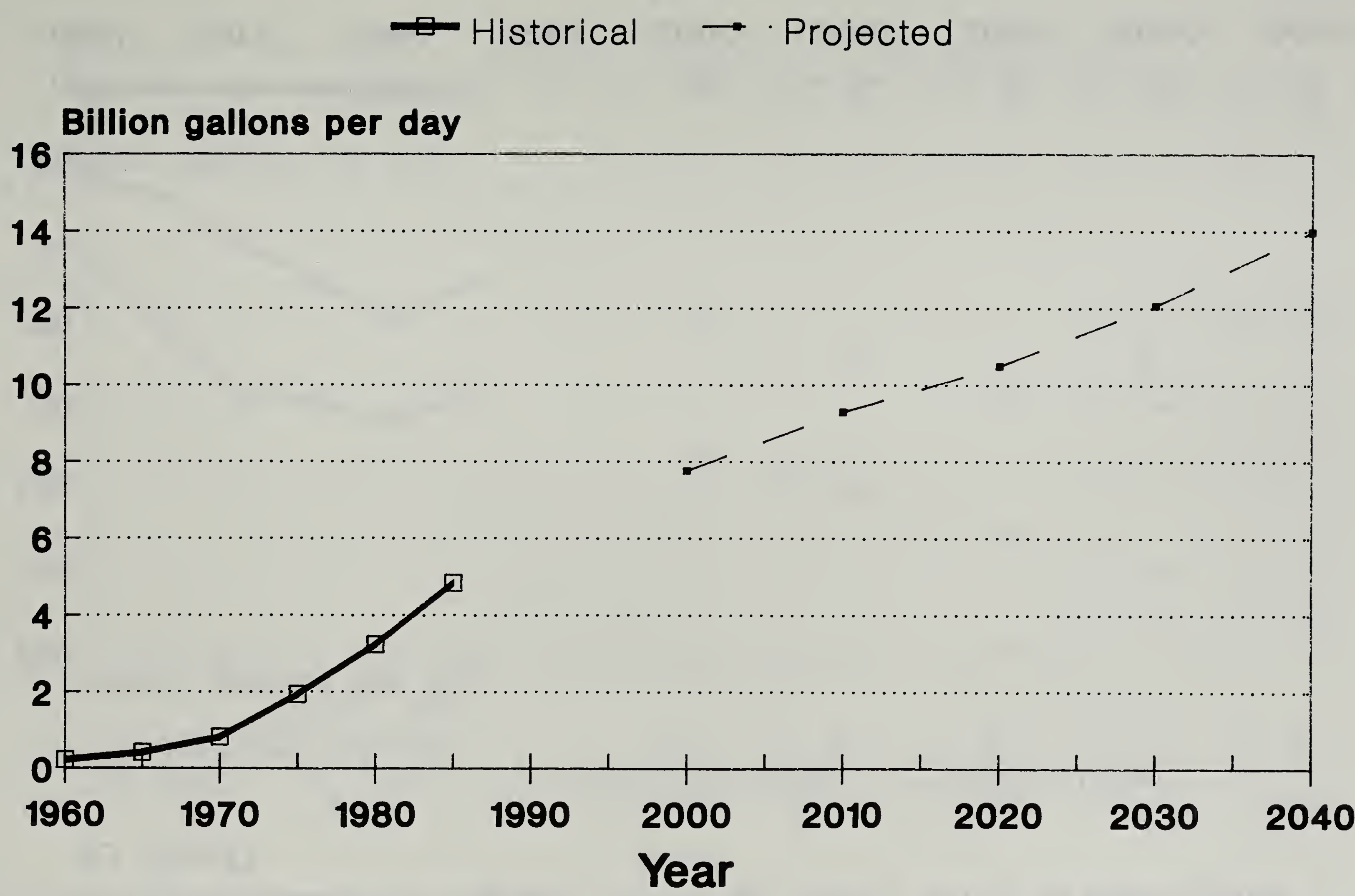
Potential for Changes in the Projections--Because electrical demands are tied so closely to GNP increases, and because GNP growth rates show long-term increases, it would take a major economic disturbance to significantly alter these long-run withdrawal and consumption projections. The Arab oil embargo of the early 1970s was just such a disturbance, and resulted in a structural change in the electricity/GNP long-term trend. Other potential events that could significantly alter withdrawals and consumption include additional major water quality legislation directed at thermal pollution, which would boost consumption and cut withdrawals, and the advent of practical uses for recently invented superconductor materials, which would reduce withdrawals.

Figure 2.4--Thermoelectric steam cooling, total freshwater withdrawals



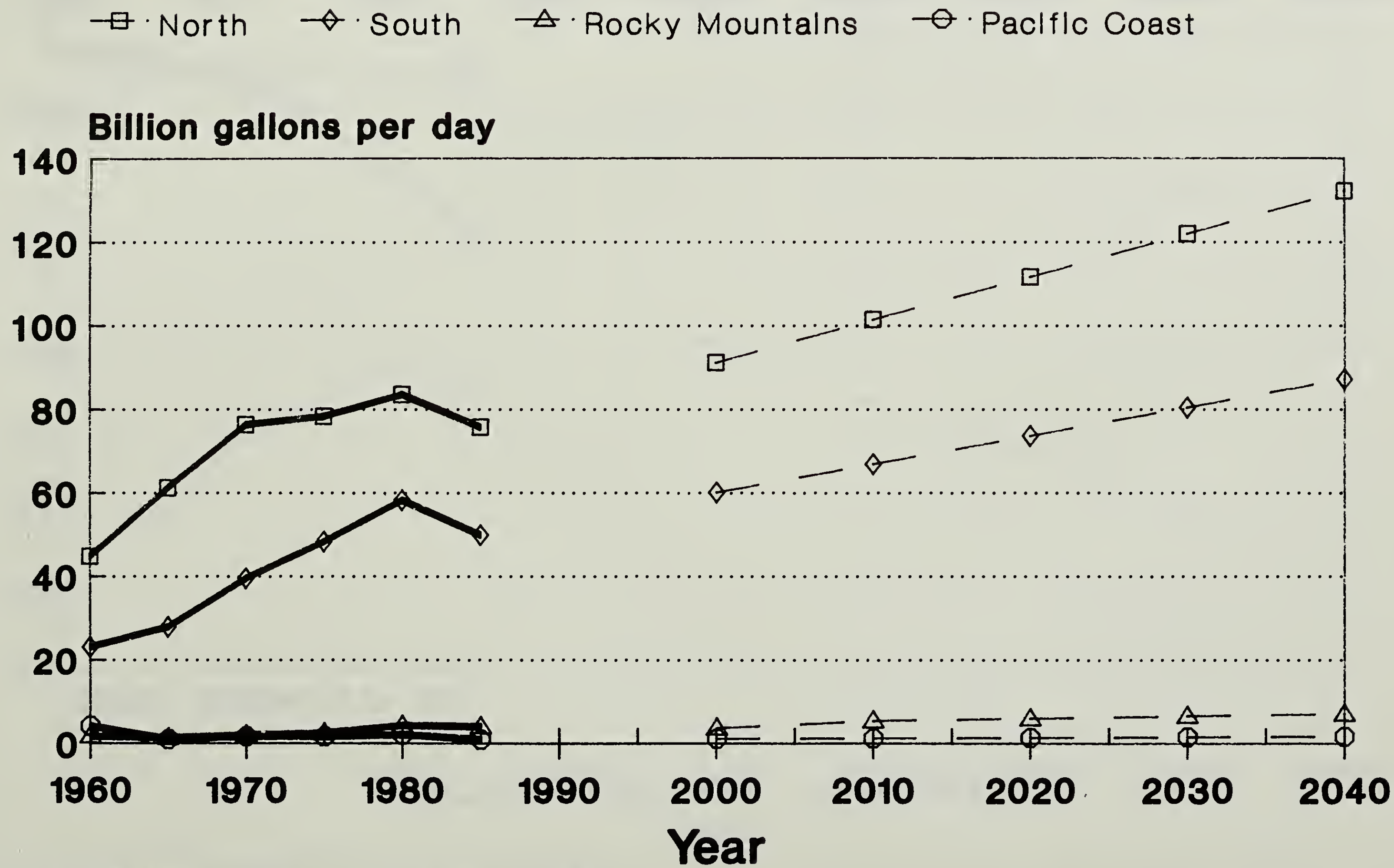
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.5--Thermoelectric steam cooling, total freshwater consumption



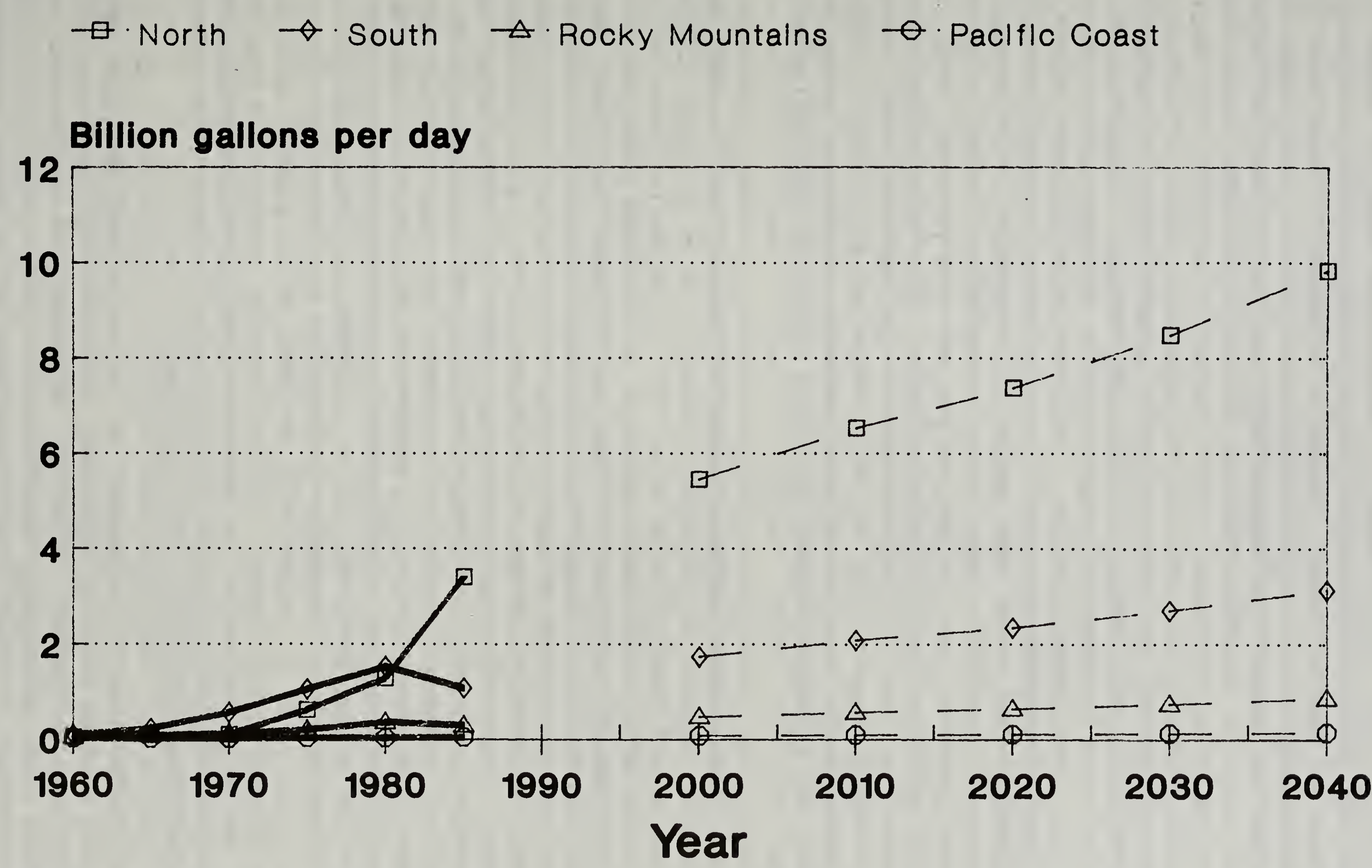
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.6--Thermoelectric steam cooling, freshwater withdrawals by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.7--Thermoelectric steam cooling, consumptive use of freshwater by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Irrigation

Description of the Use--Irrigation is the act of applying water to land to promote the growth of vegetation. In the arid and semi-arid parts of the Rocky Mountains and Pacific Coast, irrigation is needed to raise most any kind of non-native vegetation. Agricultural, horticultural, and viticultural activities all depend upon regular applications of water at frequent intervals. In many areas of the West, turf and landscape plantings around homes, businesses, along roadsides, and in recreation settings, all require irrigation too. Irrigation serves a variety of purposes in these settings. In addition to crop production, irrigation promotes beautification in residential and business settings and helps keep buildings cooler. Irrigation is often essential to recreation activities, such as managing turf on golf courses and making snow for downhill skiing. In more rural areas, irrigation of roadside plantings and property perimeters can also assist in wildfire control by establishing a buffer of less-combustible vegetation. In the more humid North and South, irrigation is used to supplement natural rainfall, providing an increase in the number of plantings per year and yield per crop, and to reduce the risk of losses during drought periods. High-valued crops, such as fruits and vegetables, are irrigated to maintain quality standards. For example, some canners and processors will not buy produce not grown under irrigation. Irrigation is also used to maintain recreation areas such as parks and golf courses, and to reduce nursery and fruit losses to late spring and early fall frosts.

Given all the possible purposes behind irrigation, and the fact that many small tracts are irrigated at different intervals, it is no wonder that estimates of withdrawals and consumption of water for irrigation purposes vary greatly. Some of the irrigation around dwellings and business establishments comes from municipal central supplies. But many recreational facilities, such as golf courses and ski areas, supply their own needs from wells or surface supplies. The bulk of the irrigation is on crops. If the acres in crop production and the water application rates can be determined, then some reliable estimates of withdrawals for irrigation can be made. Additional information about evapotranspiration must be known to reliably estimate consumption. This data is scarce. Different sources of irrigation information gather data in different ways, complicating the process of estimating the acreage irrigated. For example, the Census of Agriculture conducted by the Department of Commerce counts land as irrigated only if it is irrigated in the year of the Census. The Natural Resources Inventory conducted by the SCS every 5 years counts land as irrigated if it is irrigated in the year of the survey, or in at least two of the preceding four years. Irrigation trade associations publish statistics based upon other criteria. An extensive analysis of irrigation water requirements for croplands was conducted by Flickinger (1987) for the SCS's Resources Conservation Act (RCA) Appraisal.

Day and Horner (1987) present data on the history of irrigated agriculture. In 1889, 3.6 million acres (0.6 percent) of the 623 million acres of farmland in the U.S. were irrigated. All of the irrigated land was located in the arid and semi-arid West, principally California (1 million acres) and Colorado (0.9 million acres). In 1889, 54,000 farms were irrigating an average of 67 acres, each producing $11.50 per acre in crop value. Today, about 45 million acres of

farmland are irrigated, an average of 210 acres per farm, producing about $530 per acre. Irrigated land area has grown continuously, except for several years during the Great Depression and during 1978-1984. The growth rate has been declining since the mid-1950s, except for a brief spurt from 1969 to 1978. The proportion of irrigated farmland reached its record high of 5 percent in 1978 with approximately 50 million acres. Since then, irrigated acreage of farmland has declined by about 11 percent. During the last recession, 1982-1984, the irrigated acreage declined 4.3 million acres.

A major factor behind the rapid expansion of western irrigation during 1880 to 1900, according to Day and Horner (1987), was the need for winter feed to sustain the growing cattle industry. Simple low-head dams and stream diversion structures were constructed to flood meadows and irrigate hay and other feed crops to carry livestock over the winter. Without winter feed, it is likely that millions of acres of rangeland would have been underused and the feed grain-livestock economy of the Great Plains might never have developed. Today, 60 percent the farmland irrigated is still used to produce forage, roughage, and feed grain crops (corn, barley, oats, sorghum, hay, pasture, and silage) for livestock. Wheat and rice production--food grains for humans--slowly gained importance as a component of irrigated farmland, rising from a 10-percent share in 1889 to a 17-percent share by 1982. As agricultural technology and transportation systems improved and as consumer demand for a wider variety of crops increased, irrigated land increasingly was devoted to what were initially known as "specialty crops." Today, this list includes cotton, sugarcane, peanuts, tobacco, soybeans, vegetables, and orchards. Twenty percent of the farmland irrigated is used to grow these crops (Day and Horner 1987).

Day and Horner (1987) document how the use of irrigation differs among regions. The Pacific Coast and Rocky Mountain regions account for 85 percent of the irrigated farmland in the U.S. About 12 percent of the farmland in the South is irrigated, principally the river delta areas in Arkansas, Louisiana, and Mississippi where rice, cotton, and sugarcane are grown extensively and Florida where citrus and vegetables are widely grown. The rapid growth of irrigated farmland in the South is largely due to expansion in Georgia, now the eighth-largest state for irrigated corn production (Bajwa, Crosswhite, and Hostetler 1987). Irrigation is much less prevalent in the North, but supplemental irrigation is expanding rapidly in the Lake States and Corn Belt (Iowa, Missouri, Illinois, Indiana, and Ohio) as farmers learn how to augment rainfall to improve planting schedules and reduce weather risks. At present, about 4 percent of the farmland in the North is irrigated.

The Federal government played a large role in the development of irrigation in the 17 western states. The Reclamation Act of 1902 established the Bureau of Reclamation in the Department of the Interior to facilitate settlement of the western States by developing irrigation water supplies. Since then, the Bureau has carried out an extensive program of dam and water distribution system construction and operation. In 1982, 10.9 million acres of land were irrigated with water from Bureau of Reclamation projects. This acreage produced about $7.3 billion in gross revenues. These figures represented about 20 percent of all irrigated farmland in the contiguous U.S. and about 30 percent of the value of all irrigated farmland outputs (Day and Horner 1987).

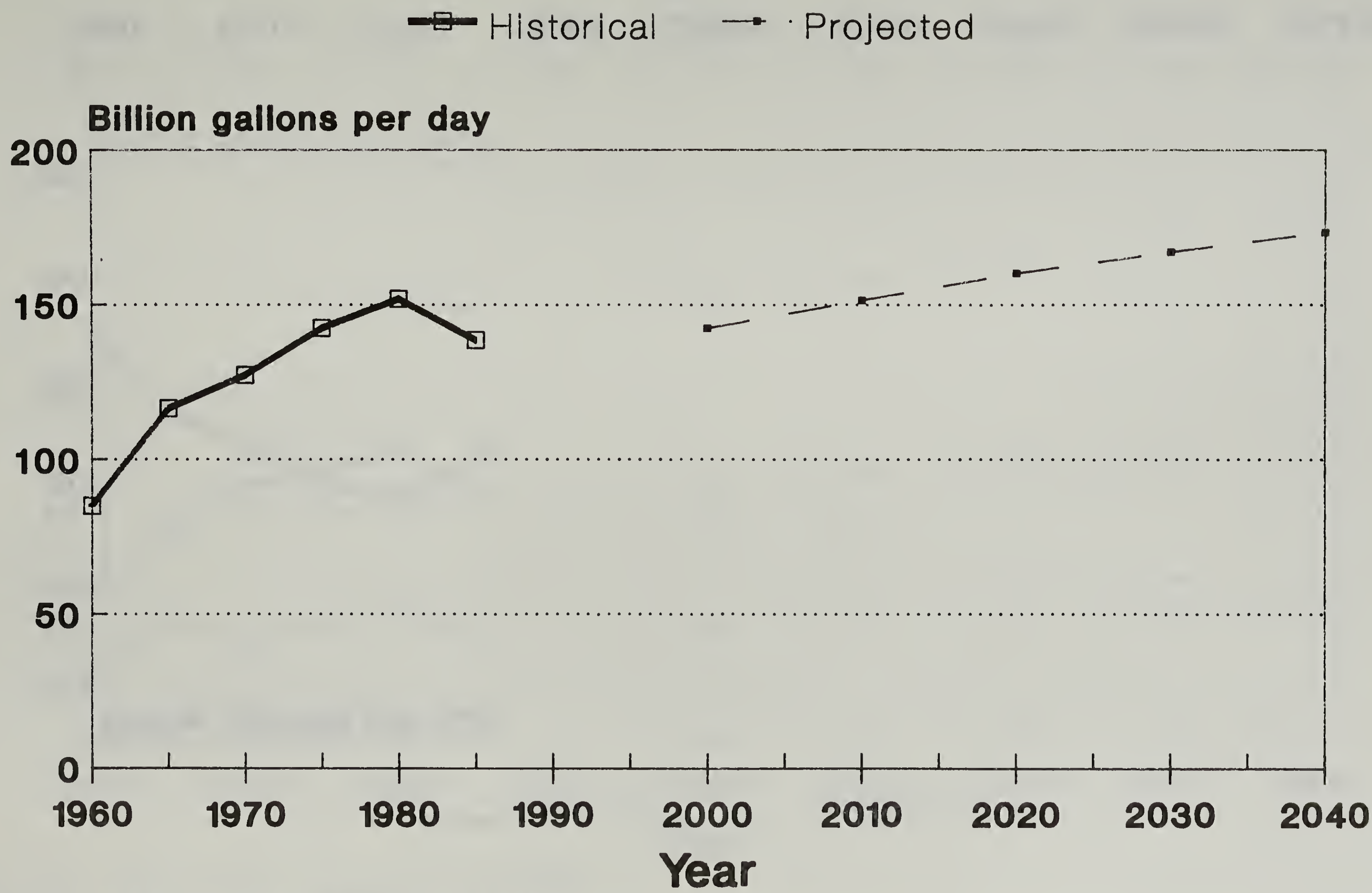
U.S. farmers use two basic types of irrigation water application systems--gravity and sprinkler systems. Gravity systems apply water using various methods, including gated pipes, ditches with siphon tubes, overland flooding, and underground porous pipes (subirrigation). Gravity systems were used on 27.5 million acres of farmland in 1984 (Day and Horner 1987). Bajwa and others (1987) reported that the farmland acreage irrigated by gravity systems dropped 12 percent between 1979 and 1984. Sprinkler systems are the more modern of the two application systems and also the more expensive. The sprinkler category include a variety of different types of equipment delivering water under pressure. The hardware includes center pivot systems, side-roll units moved either mechanically or by hand, permanent sprinklers, moveable and permanently mounted guns, and a variety of drip systems. Sprinkler systems were used on 18.3 million acres of farmland in 1984 (Day and Horner 1987). Bajwa and others (1987) reported that the farmland acreage irrigated with sprinklers dropped 8 percent between 1979 and 1984. A relatively new pressurized method currently lumped into the sprinkler figures is drip or trickle irrigation. This technique has become very popular in orchards. Its use expanded by 161 percent between 1979 and 1984, but the total acreage irrigated with this method in 1984 was still less than 1 million acres. The major virtue of drip or trickle systems is that they use much less water than conventional sprinkler systems. The major drawback of drip systems is that they cannot be used to flush salts from saline soils.

Magnitude of water use and trends--Irrigation water withdrawals in 1985 totaled 142.5 bgd, a decline of 6 percent since 1980, figure 2.8. The 1985 level of withdrawals is equivalent to the 1975 level. Irrigation withdrawals in 1985 were larger than for any other category of water use. Irrigation is also the largest consumptive user, by far. Consumption totaled 73.3 bgd in 1985, 78 percent of the total consumption by all uses, figure 2.9. It is this aspect of irrigation water use that has the most significance for current and projected future water use and development. Regional breakdowns of irrigation water withdrawals and consumption are shown in figures 2.10 and 2.11 and tables A.2, A.8, and A.14; and by source in figures A.5-A.7.

Irrigation water comes from wells, on-site surface sources, and surface sources provided by off-site suppliers such as irrigation districts and ditch companies. The principal source is from wells--56.3 bgd, 68 percent of total groundwater withdrawals. Surface withdrawals amounted to 85.8 bgd in 1985, 33 percent of total national withdrawals. Bajwa and others (1987) report that 3 of every 4 gallons from surface sources are provided by off-site suppliers. As discussed in Chapter 1, irrigators in the Great Plains rely most heavily on groundwater withdrawals while irrigators in other parts of the Rocky Mountain and Pacific Coast regions rely most heavily on off-farm suppliers.

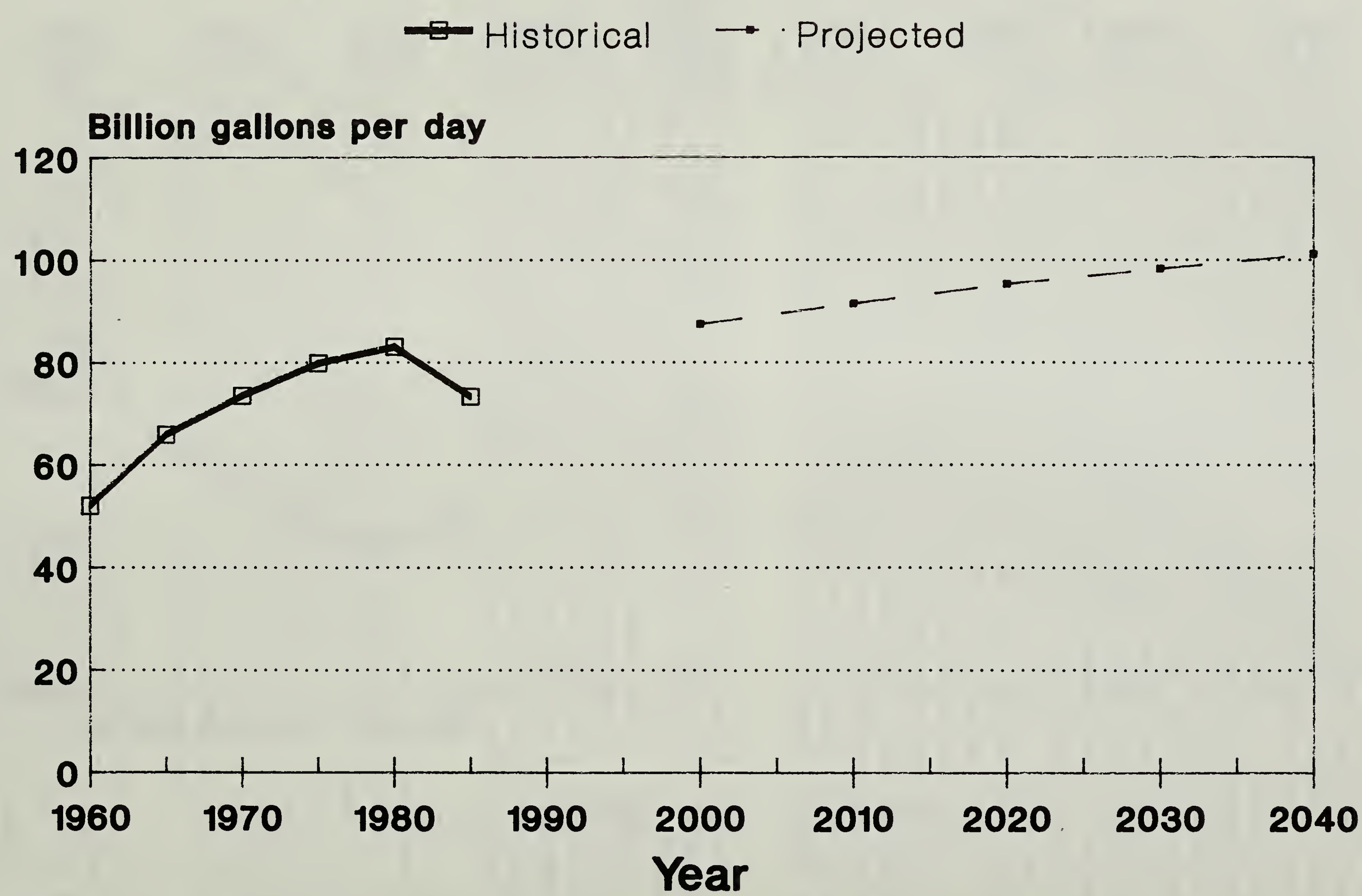
Because both wells and on-farm surface water sources must be pumped to deliver water to crops, the energy expenses of irrigating farmland can be quite large. Total energy expenses for irrigation pumping reached $1 billion in 1984 (Bajwa and others 1987). Average expenditures per acre grew by 60 percent from $20 per acre in 1979 to $32 per acre in 1984--a 41-percent growth in energy expenditures. This growth in energy costs occurred during the same time period that the farmland acreage irrigated fell by 11 percent. Viewed in this

Figure 2.8--Irrigation, total freshwater withdrawals



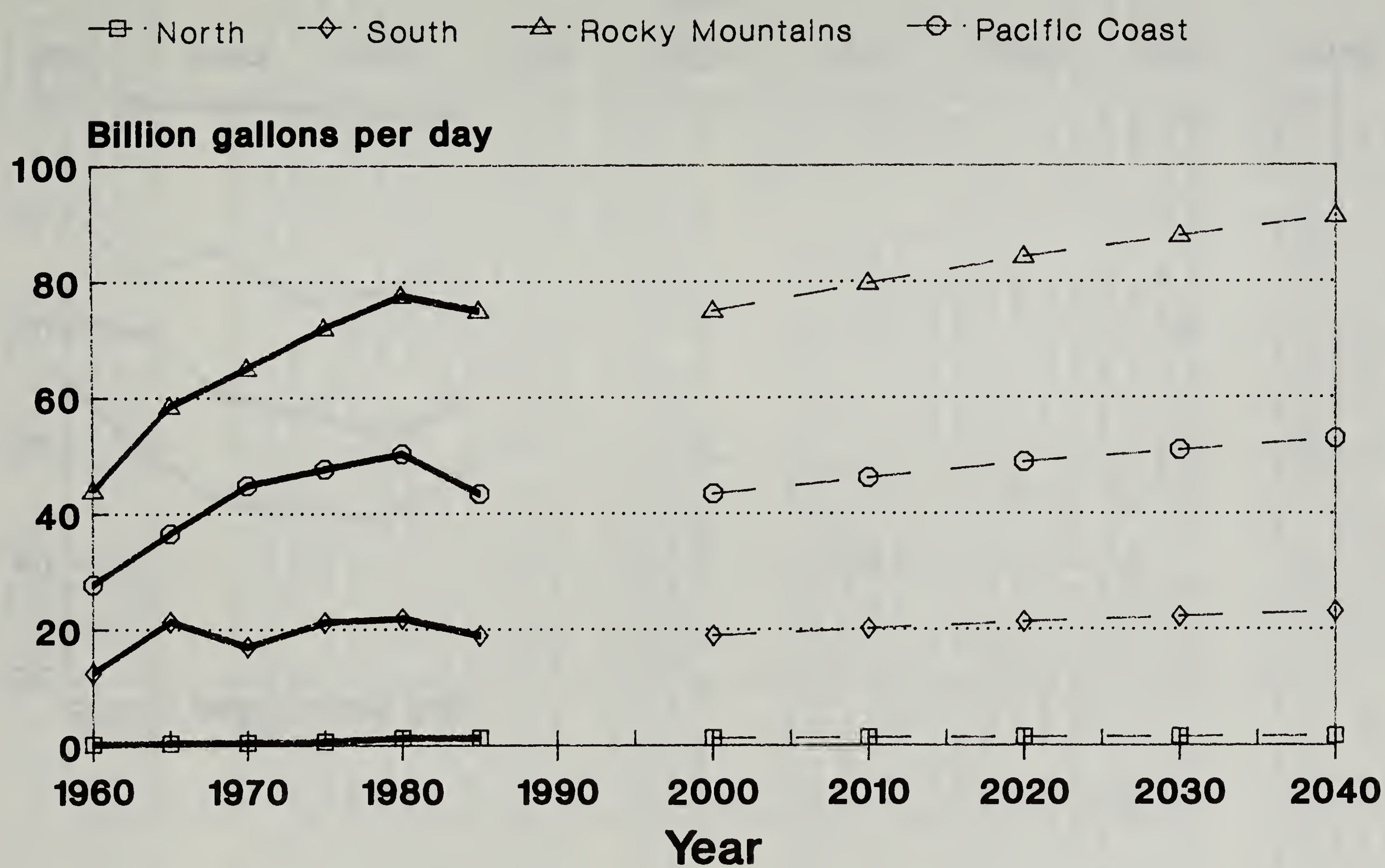
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.9--Irrigation, total freshwater consumption



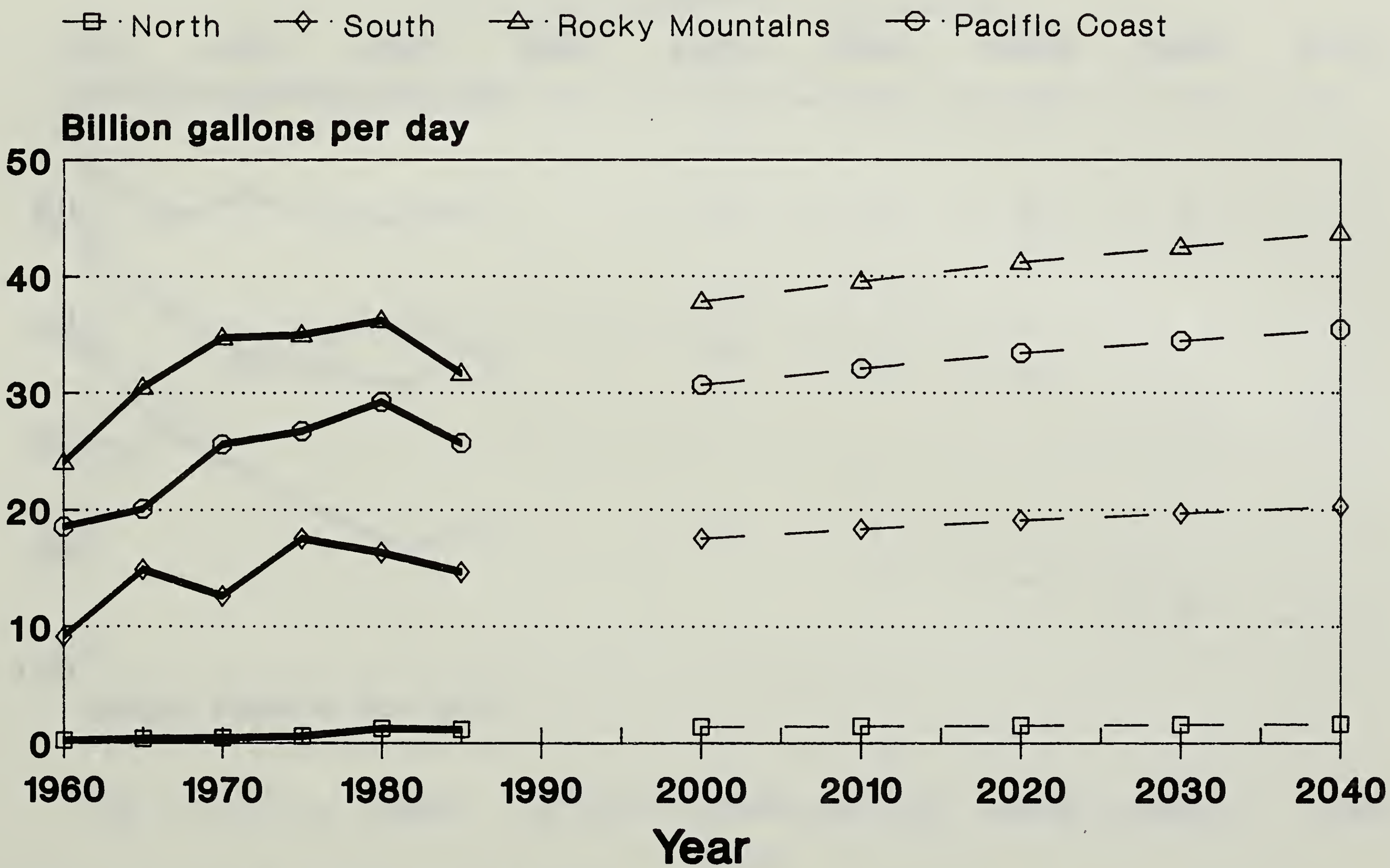
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.10--Irrigation, total freshwater withdrawals by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.11--Irrigation, consumptive use by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

context, the rise in energy costs is seen as even more dramatic. Five sources of energy are used to pump irrigation water--electricity, natural gas, liquid propane (LP) gas, diesel, and gasoline. Electricity dominates with a 58-percent share, natural gas has a 19 percent share, and diesel a 17 percent share of the irrigation pumping energy market. Since 1979, electricity usage has grown in importance, natural gas has declined, and diesel held steady (Bajwa and others 1987).

Flickinger (1987) estimated the water withdrawals by farmers for irrigating crops in 1982 was 129.6 bgd--about 87 percent of total irrigation withdrawals for that year estimated using USGS data (Solley and others 1983, and Solley 1987). The fundamental difference between the Flickinger and USGS estimates is that Flickinger carefully estimated withdrawals and consumption only for agricultural uses, while the USGS estimates include withdrawals for non-agricultural uses. In some water resource regions, Flickinger's estimates were larger than the 1982 estimate interpolated from USGS numbers. This Assessment concurs with the estimates made by Flickinger for agricultural uses and uses them as a base. In water resource regions where USGS estimates are larger than Flickinger's, the USGS numbers are used to account for non-agricultural irrigation. The pattern of water resource regions where USGS estimates were higher fit the expectation of regions having significant non-agricultural irrigation. Thus, the irrigation withdrawals and consumption numbers in this Assessment are somewhat larger than the irrigation estimates for 1985 by Solley (1987).

Bajwa and others (1987) contains detailed information on the farmland irrigation situation in each State, including the methods, sources, and expenses of irrigation and comparisons of the average value of farm capital for farms using irrigation compared to dry land production practices.

<u>Potential for Changes in the Projections</u>--Irrigation water usage is projected to grow at a much slower rate over the next 50 years than over the previous 25 years. From 1960 to 1985, the average annual growth increase was 2.1 percent. From 2000 to 2040, the projected growth rate is 0.5 percent. A major reason is the continuing increase in pumping costs. Energy cost increases and aquifer declines both increase pumping costs. Increased pumping costs reduce the net return per acre, narrowing the advantage enjoyed by irrigated crop production over dry land crop production. The point has already been reached in the some parts of the Southern Great Plains where net returns from irrigated crop production are lower than for dry land crop production. As soon as irrigation equipment is depreciated and paid for, many farmers are idling it. If crop prices rise, the additional income may restore the cost advantage to using irrigation.

Bureau of Reclamation water pricing policies have come under scrutiny recently by interests seeking to reduce crop production subsidies. Irrigators are charged for water obtained from Bureau projects, but the prices are quite favorable for the users. If prices increase, then irrigation water use would be expected to decline below the projected levels. Also, a shift away from irrigating low-valued crops, such as alfalfa, hay, and pasturage, would likely occur.

Technology advances in irrigation are expected to continue due to the expected cost increases in water pumping. Chief among the new technologies that will be implemented in the near future are drip and trickle irrigation systems. These enable the farmer to control water applications much more precisely and have much lower losses to evaporation and excess runoff. For example, Clark and Finley (1975) showed that evaporation loss from sprinklers is an exponential function of wind velocity and that in the southern plains, an average of 17 percent of the water passing through a standard sprinkler nozzle evaporates before reaching the ground or target vegetation. Gilley (1983) described other management practices that could be employed to reduce energy and related irrigation costs. To the extent that such practices are adopted, the withdrawal and consumption projections could change.

Municipal Central-supplied Water Use

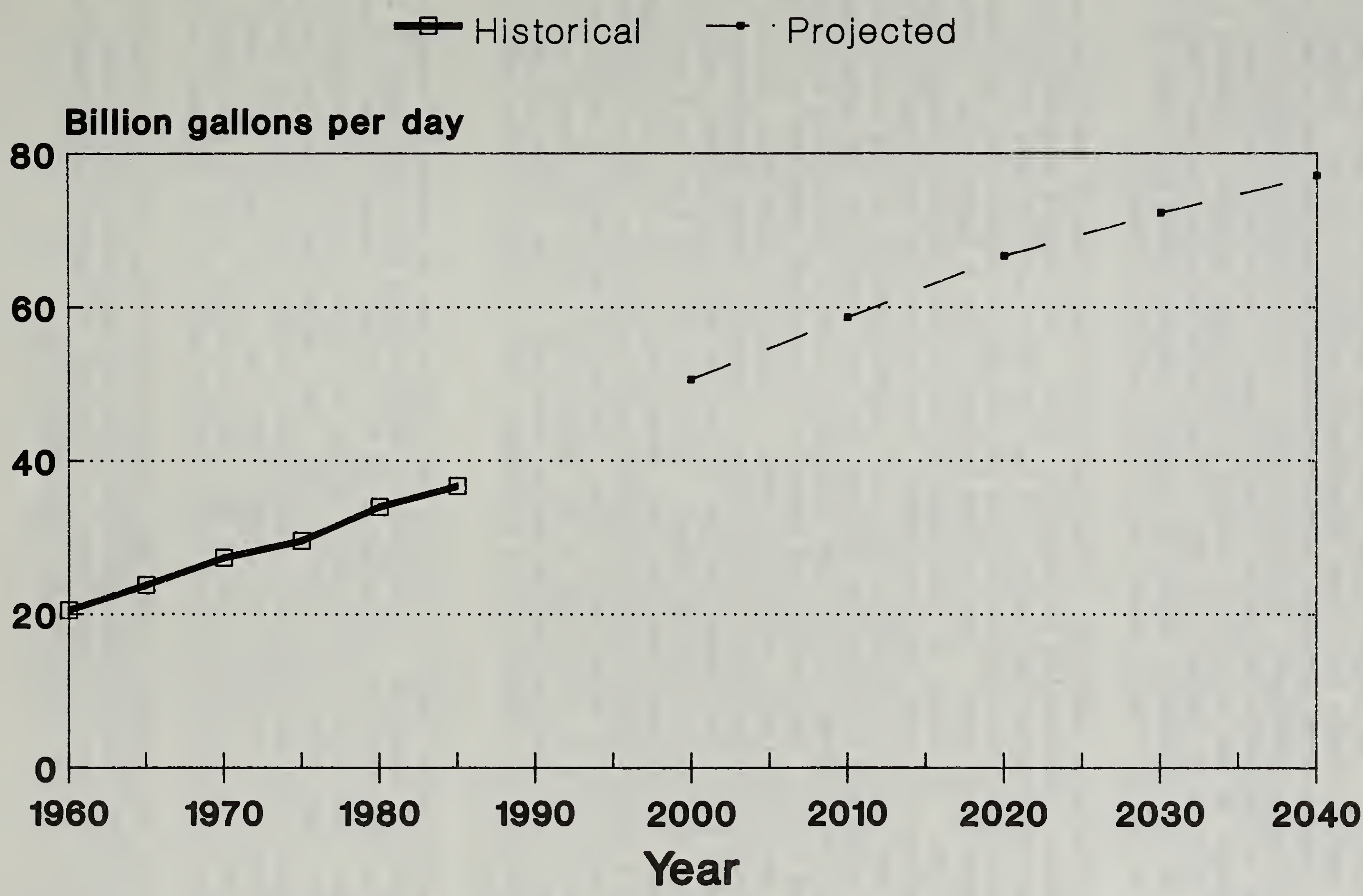
Description of the use--Municipal central-supplies refers to water withdrawn by public or private water supply utilities who distribute treated water through a network of pipes to household, commercial and industrial users. This use category stands in contrast to domestic and industrial self-supplied use--those parties each withdraw water for their own needs from surface or groundwater sources. Municipalities may contract with a private firm to supply water or have their own supply and treatment systems. For example, the city of New Haven, CT and surrounding towns obtain their water from the New Haven Water Company, a private firm. Other cities, such as Reading, PA, have a water supply agency that is part of the local government.

Municipal systems serve a variety of users. Foremost are individual households, but commercial establishments--stores, restaurants,light industry--are also usually served by municipal supplies. There comes a point for many industries when a corporate decision must be made whether or not to rely upon municipal supplies for their entire water needs. Such a decision is fundamentally one of cost. A firm may use water in their manufacturing process as a major component of the product, as in brewing beer, or as an adjunct, such as for cooling in steel mills. In the former case, the quantity required by a new facility is so large that it could overwhelm the municipal supplier's abilities to provide it. In this case, it is often cheaper for the firm to develop its own supply. In the latter case, water of a lower-than-potable quality is needed, so paying a municipal supplier to treat the water to potable levels is again more costly than developing an independent supply. Finally, if high costs are associated with production process interruptions due to water shortages, then an auxilliary private supply may be developed as a safeguard against interruptions.

In addition to providing water for household, commercial and some industrial uses, municipal central-supplies also include water for public uses. Public uses include fire protection, street washing, municipal parks and swimming pools.

Magnitude of Water Use and Trends--The total water withdrawals for municipal supplies reached 36.7 bgd in 1985, an increase of 8 percent over 1980. The trend in municipal withdrawals has been one of steady increases over the past 25 years, table 2.1 and figure 2.12. Consumption, on the other hand, showed a

Figure 2.12--Municipal supplies, total freshwater withdrawals



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

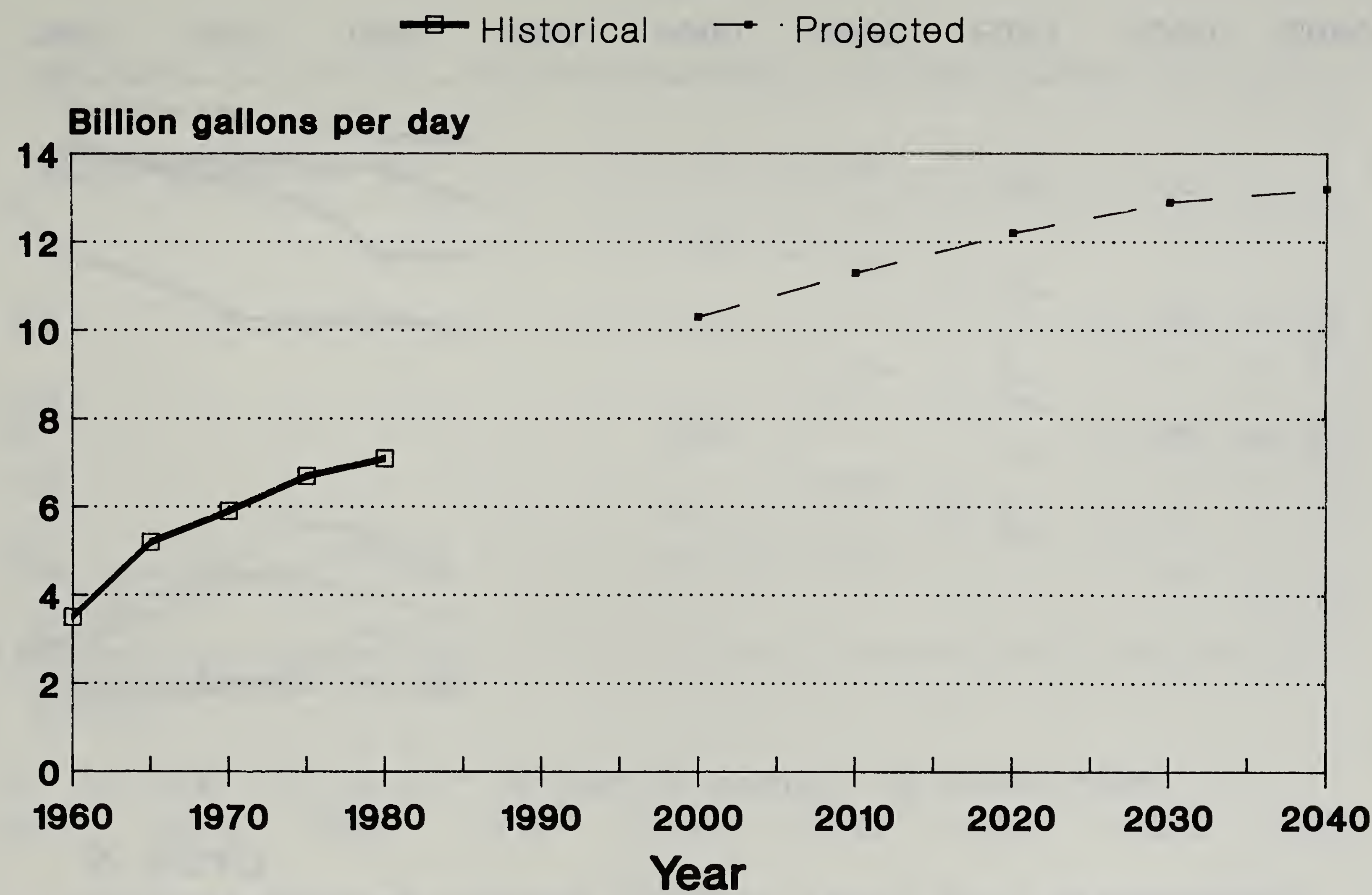
decline since 1980 by 13 percent to 6.1 bgd, table 2.2 and figure 2.13. Region withdrawal and consumption patterns are shown in figures 2.14-2.15. Historically, the larger cities have used surface water as the municipal source while smaller towns have used groundwater as their source. Between 1980 and 1985, there was an increase in the groundwater withdrawn and a decline in the surface water withdrawn, figures A.8-A.9. This pattern supports the observed trends in population migration from cities to more rural settings. The percentage of the population served by municipal systems increased 2 percent since 1980 to 83 percent in 1985. This percentage may be near the upper limit that can be reasonably served by central systems given the costs of extending water mains into rural areas having low population density.

Some evidence is emerging in the per-capita use rates of municipal supplies that water conservation has begun to occur. Per-capita household use in 1980 was 120 gallons per day (gpd), 117 gpd in 1975, and 115 gpd in 1970. The 1985 data show per-capita household use at 105 gpd--a significant reduction given the short-term trend. Two factors probably play a large role in this reduction. The first is that municipalities have recently begun major renovations of water supply systems. New technology developed in the last 20 years has given municipalities a clear understanding of the status of leaks in water mains and distribution systems for the first time and also a means of fixing the problems without the tremendous cost of excavating and replacing the leaking mains. Excavation and repaving have always been the most significant costs associated with repairing leaks. Miniature television cameras and new leak detection developed in the 1970s now permit direct observation of the inside of pipes and determination of leaking sections without excavation. Pipe sections and joints needing repair can be pinpointed for the first time before digging. Techniques have also been developed to reline existing pipes with plastics and polymers having improved leak resistance, again with excavating major sections of water main. Thus, technology has made it much more economical to fix leaks than to add additional water withdrawal and treatment capacity. Because per-capita use is measured by the volume of water entering the distribution system at the treatment plant, repairing the leaks reduces per-capita use.

The second major factor affecting per-capita use is household adoption of water conservation measures. A variety of improvements have been made in residential plumbing fixtures and home appliances to cut down on water use. Showerhead that use less water, water-saver cycles on laundry and dish washers, commodes that use less water per flush have all been developed since the 1960s. They have gradually been adopted in sufficient numbers that they are now making a contribution to reducing per-capita water use. Per-capita use trends also show some regional variation--use in the West is higher than in the East. Lawn watering is likely the key to understanding much of the regional variation.

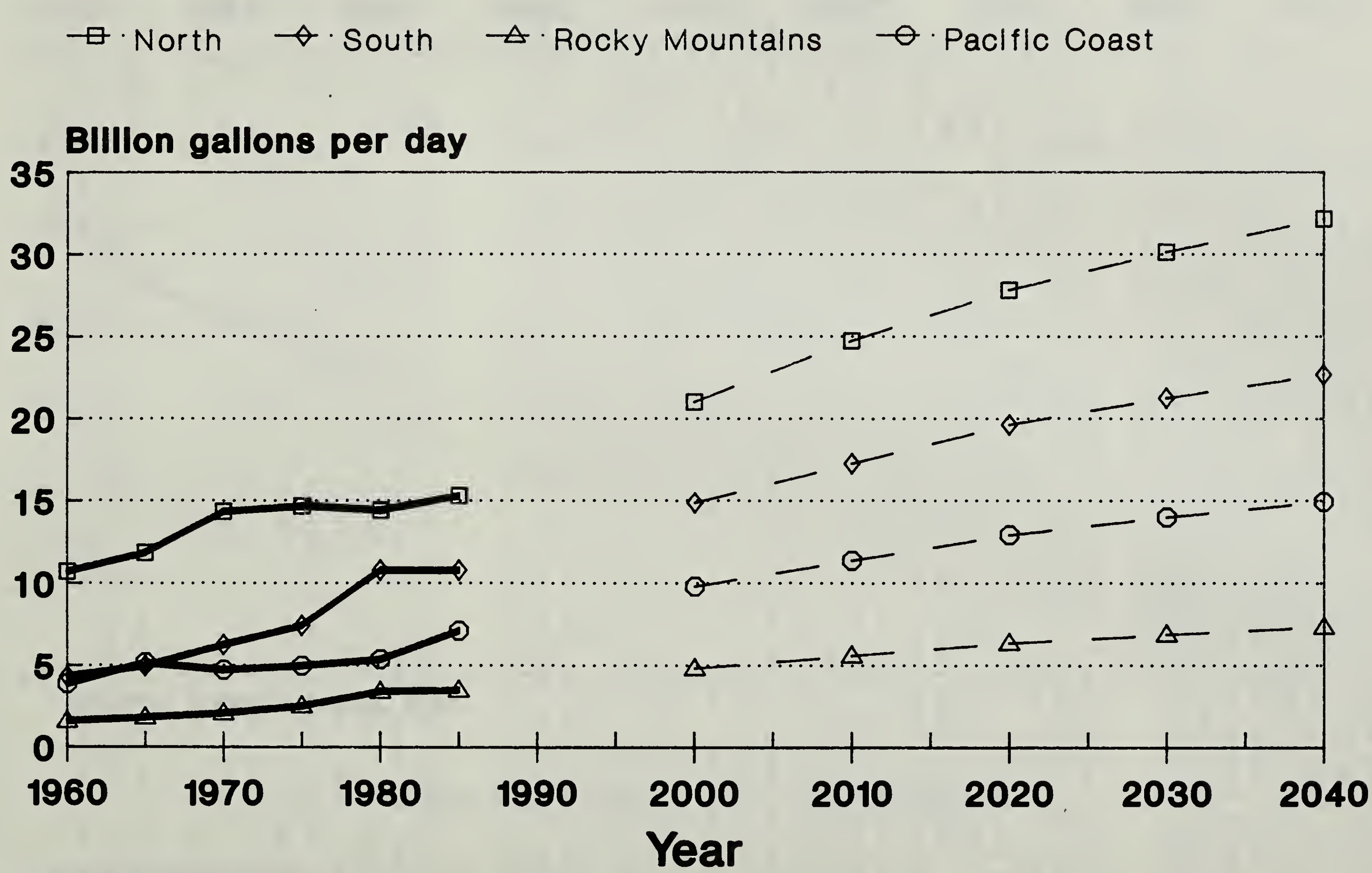
<u>Potential for Changes in the Projections--</u>Over time, water main servicing and water-saving fixtures and appliances will become more heavily used. The extent to which adoption of these items is hastened or delayed will cause the actual municipal withdrawal level to fluctuate also.

Figure 2.13--Municipal supplies, total freshwater consumption



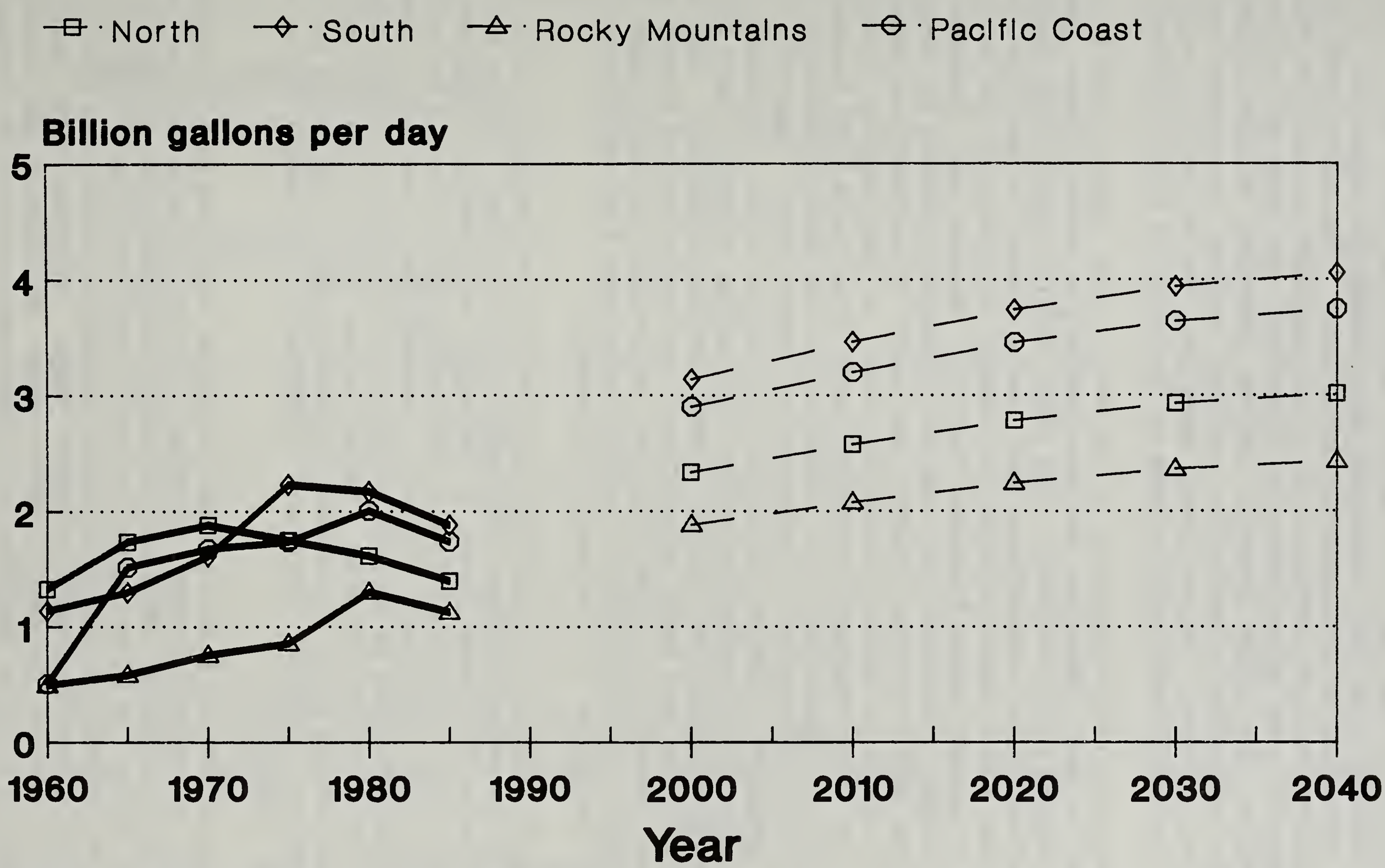
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.14--Municipal supplies, total freshwater withdrawals by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.15--Municipal supplies, consumptive use by region, 1960-1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Industrial Self-supplied Water Use

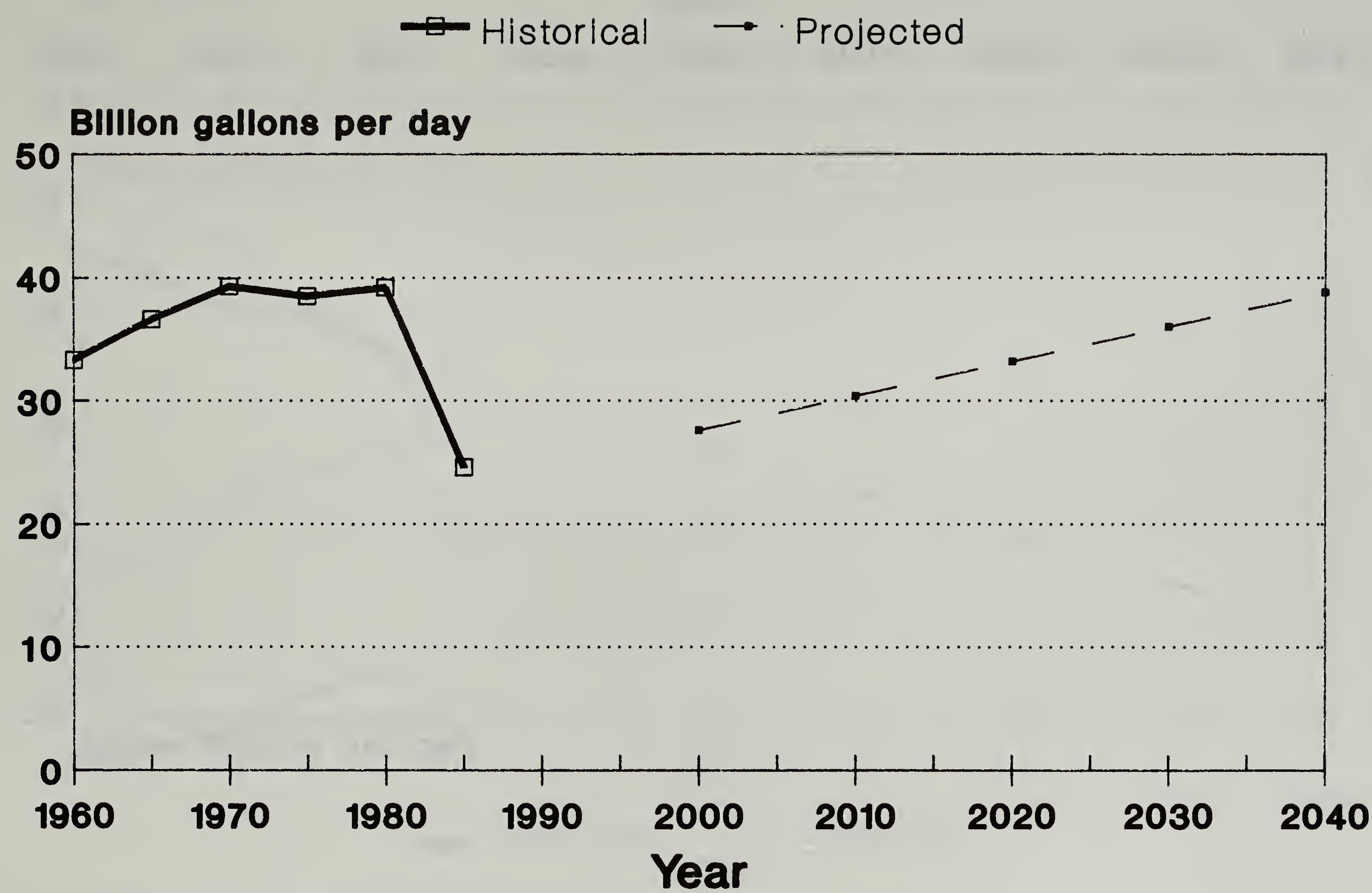
Description of the Use--Self-supplied industrial water use is categorized in this Assessment as water withdrawn and consumed by industries for its own use, other than cooling thermoelectric powerplants. The major water using industries that have developed their own supplies include the steel industry, the chemicals and allied products industries, the paper and allied products industries, the mining industry, and the petroleum refining industry. Water is used by industries primarily for cooling, washing, conveyance, and as part of the final product. As previously described, the decision to supply ones own water is a corporate decision made on the basis of cost-efficiency.

The water quality legislation of the early 1970s imposed more stringent regulation upon industries who were discharging waste streams. Many of these firms supply their own water. The water quality regulations required industries either to discharge their waste streams to municipal systems, which were then authorized to charge the industry for treating the wastewater, or to build a separate waste treatment facility. Because many industrial waste flows contain pollutants that are not effectively removed by conventional municipal waste treatment plants, many small to medium-sized municipalities were reluctant to handle industrial flows. If they decided to accommodate the flow, the costs charged the industry were often quite high because special treatment processes had to be installed for the entire (municipal plus industrial) flow volume. Consequently, constructing a separate industrial waste treatment plant was often the strategy selected. Building such plants was costly. In an effort to reduce the capital expenses, much effort was devoted to reducing the volume of waste needing treatment. Just as municipalities have begun an ambitious leak detection and repair program, so did many industries. Consultants and contractors providing these services flourished. Opportunities to recycle water were also explored in an effort to reduce the volume of flow needing treatment.

Magnitude of Water Use and Trends--Industrial self-supplied water withdrawals declined 37 percent between 1980 and 1985 to 24.5 bgd, figure 2.16. This level is far below the recent trend in industrial withdrawals; withdrawals have hovered at 39 bgd since 1975 and have been greater than 33 bgd since 1960. Surface water withdrawals dropped 31 percent since 1980 and groundwater withdrawals dropped 55 percent, tables 2.1, A.4, and A.10 and figures A.10-A.12. Consumption increased 9 percent since 1980 to 5.5 bgd, tables 2.2 and A.15 and figure 2.17. Increased recycling would be expected to increase consumption. Regional patterns in withdrawal and consumption are shown in figures 2.18-2.19.

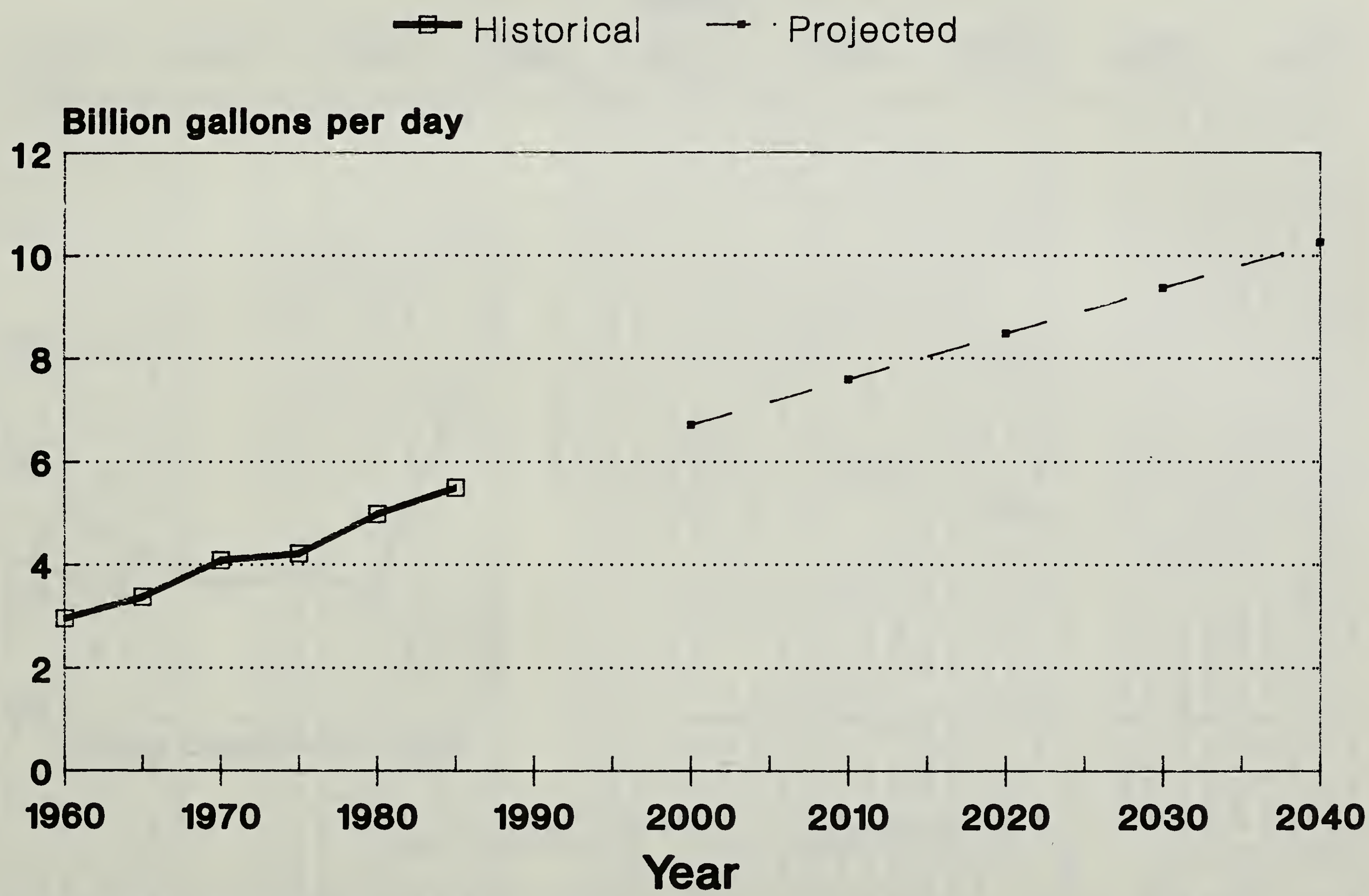
The projections of industrial self-supplied water use are the weakest of all the six categories of uses. Figures 2.16 and 2.18 show how the historical trend has fluctuated--they have no significant association with the historical trends in GNP. A major reason has to do with the kinds of industries that are heavy water users in comparison to the kinds of industries that have been contributing to GNP growth in recent years. The heavy water users have shown mixed performance the past 10 to 20 years. While paper and allied products and chemicals and allied products have shown some increases in outputs in recent years, steel-making, mining, and petroleum refining have not fared as well.

Figure 2.16--Industrial self-supplied water, total freshwater withdrawals



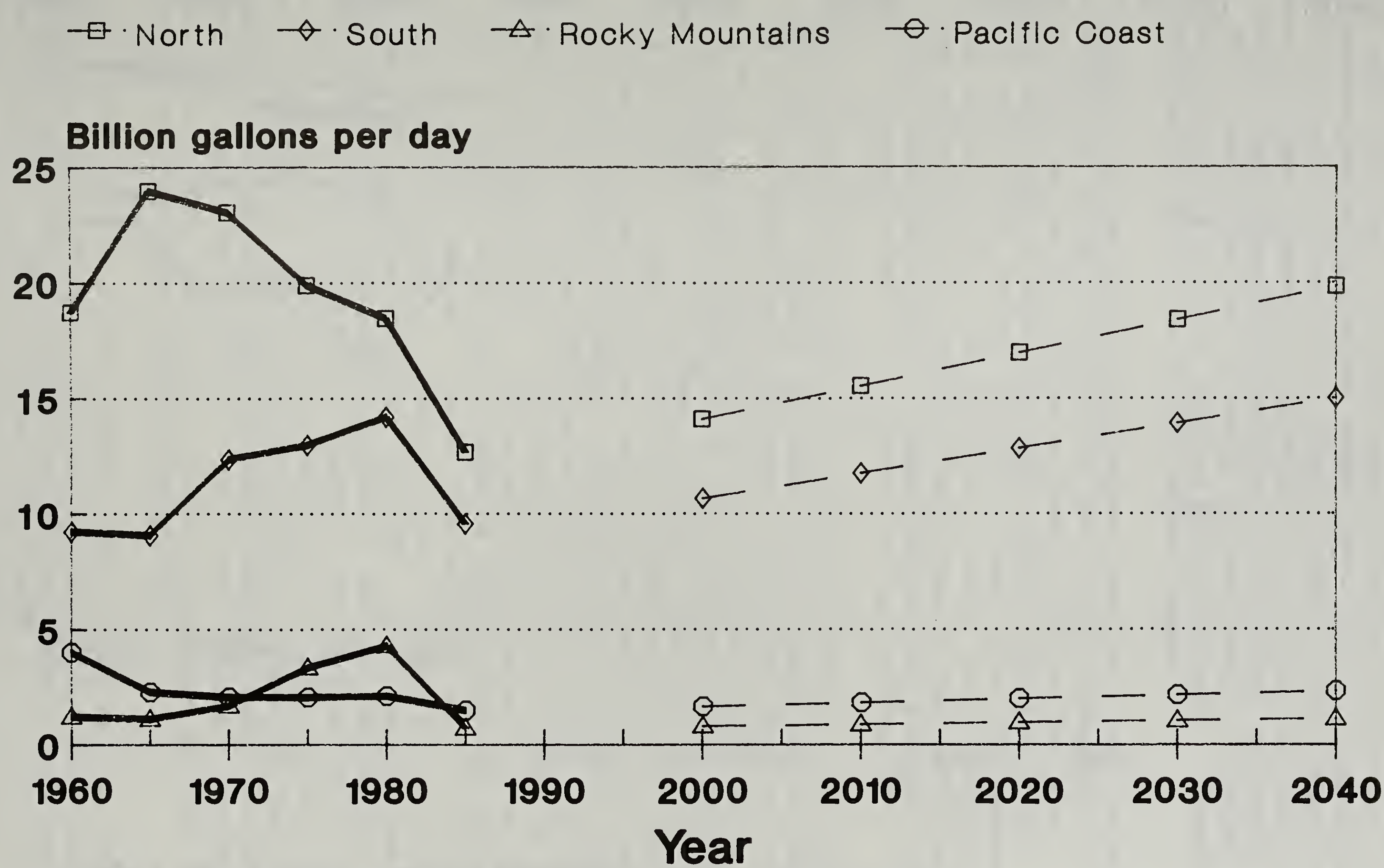
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.17--Industrial self-supplied water, total freshwater consumption



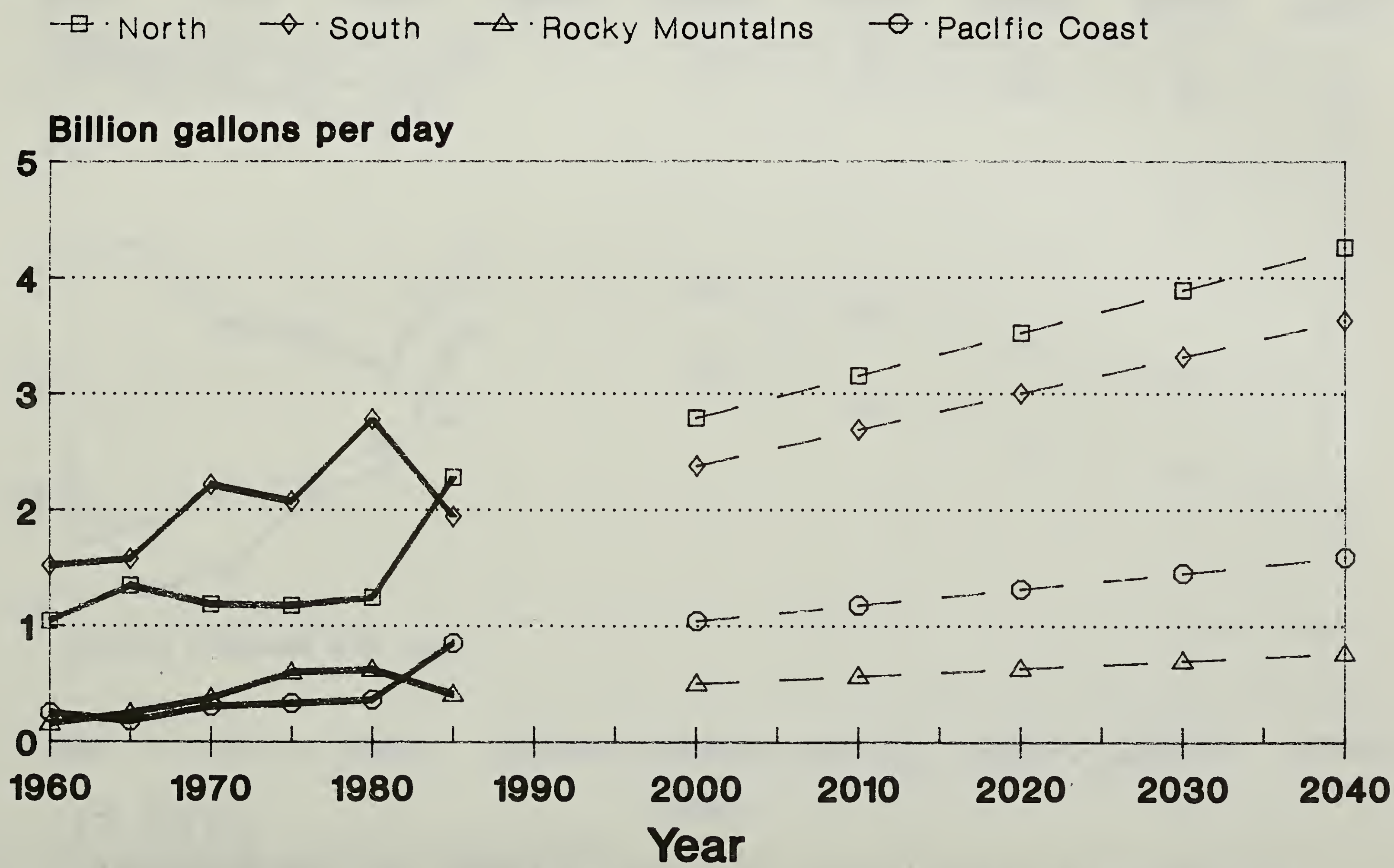
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.18--Industrial supplies, total freshwater withdrawals by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.19--Industrial supplies, consumptive use by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

In particular, the steel and petroleum industries have taken a beating in the recession of the early 1980s. Growth in those industries is presently moribund. In addition to more stringent water pollution regulations, these same industries have had to comply with stiffer air pollution regulations. The consequence is that much of the capital normally used for plant expansions or to become more efficient producers was diverted to pollution abatement; thus, the industries are overburdened with obsolete or inefficient production facilities. That these industries are among the most heavily unionized industries remaining in the U.S. has added an additional layer of complexity to the process of adjusting to the new production environment.

<u>Potential for Changes in the Projections--</u>Because the historical trends are not very responsive to the basic assumptions used in this Assessment, the potential for changes in the projections is great. Because the major industries using self-supplied water have been heavily impacted by the recession of the early 1980s and the recovery of some is not yet underway, it is impossible to say how much of the reduction in water use is attributable to long-term trends versus short-run economic conditions in the industries. Certainly if these industries were all vibrant and had rosy futures, the projections of self-supplied water use would be increasing over time.

The U.S. economy has shifted in recent years from one driven by the engines of basic heavy industry--steel, mining, railroads--to an economy driven more by "high tech" and service industries--computers, electronics, food service, health care. The U.S. economy was pulled from the depths of the Great Depression, in no insignificant part, by the mobilization of the basic heavy industries for World War II. The economy literally fought its way out of the Depression. In the past 20 years, much of the production in these heavy industries has moved to other countries, such as steel-making to the Far East. Consequently, our environment is cleaner. The Ohio River no longer flows rust-red south of Pittsburgh, PA; West Virginia's rivers are no longer yellow with the sulfuric acid from coal mining; the Cuyahoga River below Akron, OH no longer burns in Cleveland's harbor. But we have paid a price for our cleaner environment, and it has not only been in terms of expenditures for pollution control facilities, it has been in terms of jobs exported along with the heavy industry that has gone elsewhere. Ignatius (1988) reported that 245,000 steel workers have lost their jobs between 1979 and 1988. In the decade from 1977 to 1986, 24 steel companies disappeared in mergers or declared bankruptcy. Firms that survived drastically reduced their capacity. USX Corporation, the successor to U.S. Steel, has reduced its steel-making capacity from 33 million tons per year in mid-1983 to 19 million tons in 1987. Railroads, barge lines, and coal companies--all dependent upon the steel industry--shared in the decline in business and economic activity. Of course, a number of cost factors contributed to these changes; one was the capital, operation, and maintenance costs of water and air pollution cleanup and abatement.

The prevailing view of the U.S. economy beyond 1990 is that service industries will continue to grow in importance. Service industries tend to use much less water than heavy industry, largely because cooling and washing requirements are much lower, so volumes of water to be treated will grow at a slower rate than in the recent past. Waste flows from service industries fall into two categories. The first are flows very similar to household waste flows. Firms

in industries such as food or financial services generate these kinds of flows and treating them at municipal plants will cause no unusual problems other than making certain sufficient volumetric capacity exists. The second type of waste flow from service industries are very dissimilar from conventional household flows. These kinds of flows contain pollutants, such as products of biochemical reactions, that are more difficult to handle in conventional waste treatment plants than the sediments and BOD for which they were designed. Specialized in-plant treatment facilities using advanced methods such as reverse osmosis, activated carbon adsorption, or incineration will be needed to treat these waste flows. The trend towards providing this level of treatment at the plant where the waste flows are generated will increase.

The industrial self-supplied water use projections in this Assessment are based on a period of time when industrial production is in a state of flux. Consequently, they are subject to uncertainty. In the above discussion on factors that might influence how the projections change, the general conclusion is that the rate of increase in volumes has ceased, unless a major recovery of the heavy water-using industries occurs. A decline in the total flow volume for self-supplied industries may have already begun; the 1990 Geological Survey data will be needed to confirm that point. The other general conclusion is that the character of the waste flows is also likely to change as service industries emerge as a more prominent sector of the U.S. economy.

Domestic Self-supplied Water Use

Description of the Use--Water for rural use includes water for household consumption, drinking water for livestock and other uses such as dairy sanitation, evaporation from stock-watering ponds, cleaning, and waste disposal. Because water for these uses is drawn largely from wells serving individual dwellings or business locations, and because these water supply systems are rarely metered, few "hard" data on rural water use exist. Consequently, the information presented in this section and the subsequent one on livestock use represent the best estimates of the Geological Survey on trends in water use in rural areas.

The total rural use quantity is broken down into two components--domestic self-supplied use and livestock use. The former use includes estimates of household use and use around the home, such as vehicle washing and lawn watering. Waste disposal in rural areas is also individualized, primarily through septic systems. The latter use category includes estimates of livestock consumption and sanitation, such as manure disposal via holding lagoons and pasture irrigation. Livestock use will be discussed further in the next section of this chapter.

Domestic self-supplied use is mainly a function of the population not served by municipal central-supplied water systems. The Geological Survey estimates the number of people who supply their own water by subtracting the number served by central systems from the total U.S. population. The percent of population served by domestic self-supplied water has dropped from 31 percent in 1955 to 25 percent (1960) to 21 percent (1965) to 19 percent (1975) to 17 percent in 1985. So the population trend has slowed in the past decade compared to the former two decades.

In the 1930s and 1940s, many rural households did not have indoor plumbing. Per-capita water use rates on the order of 10 to 15 gpd were common. Wind, and later electricity, was commonly employed to fill elevated water tanks that supplied water by gravity to plumbing and faucets--these systems provided running water. In 1955, about 20 percent of rural homes had running water, with per-capita use between 50 and 60 gpd. Since then, more and more rural households have been supplied with electric water pumps, commonly filling a pressurized tank on demand. Installation of modern appliances in rural homes served by pressurized systems has increased per-capita consumption to about 80 gpd. Houses served by municipal central supplies use about 105 gpd per-capita.[3] The current difference in per-capita water use is due in part to differences in water pressures between the individual and municipal systems. Municipal systems commonly operate at 60 pounds per square inch (psi) of water pressure. Individual systems commonly operate between 25 and 40 psi.

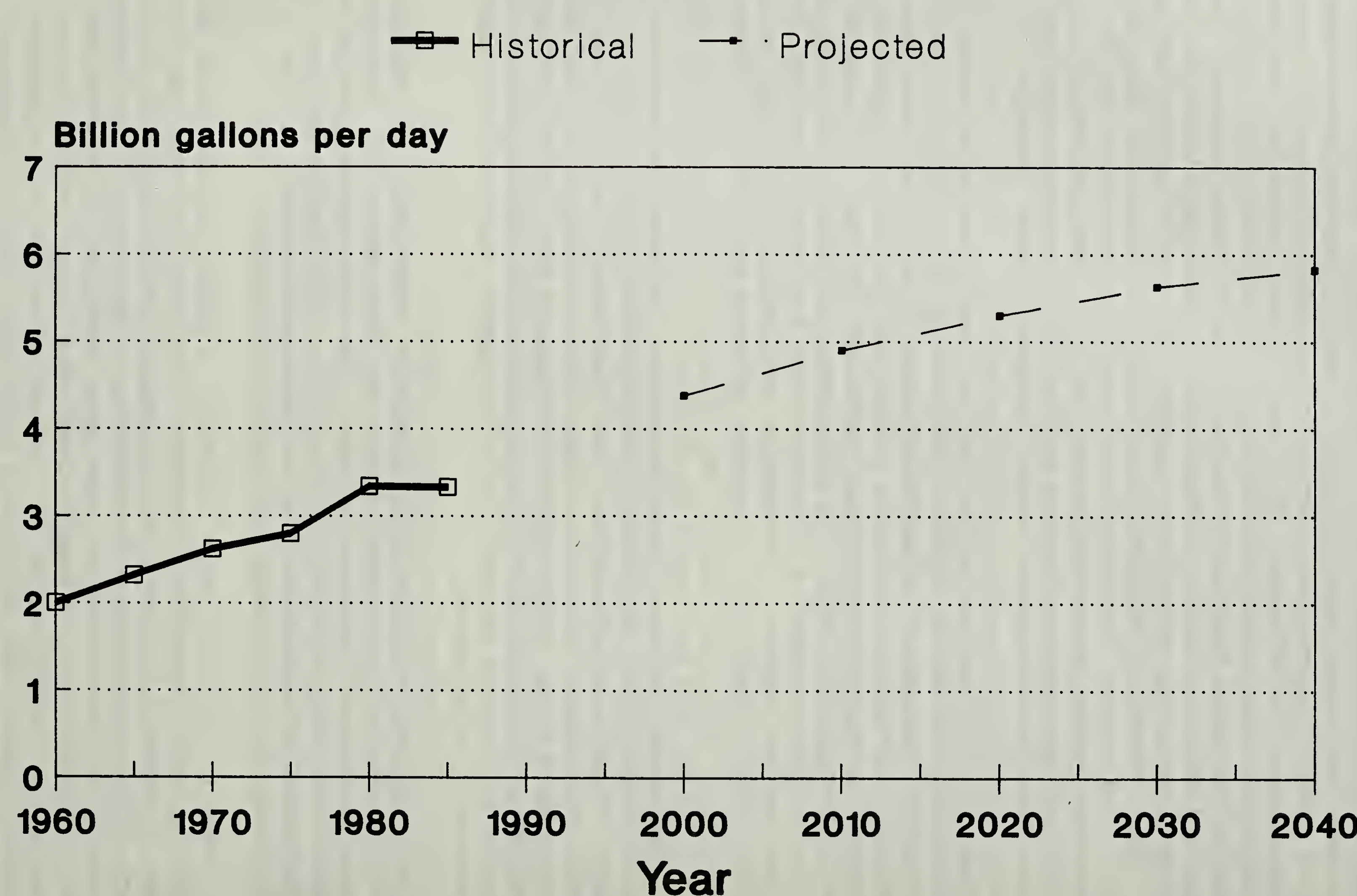
<u>Magnitude of the Water Use and Trends</u>--Total withdrawals for domestic self-supplied water use were 3.3 bgd in 1985, a drop of 0.4 percent from 1980, figure 2.20. The population served by domestic self-supplied systems remained essentially constant at 40 million people over the same time period. Groundwater is the primary source of water for domestic self-supplied use, figures A.13-A.14. In 1985, only 2.5 percent of domestic self-supplied water came from surface sources, a 50 percent drop from the 5.1 percent in 1980 that came from surface sources. Consumption totaled 1.6 bgd in 1985, a drop from 2.0 bgd in 1980, figure 2.21. Regional patterns are shown in figures 2.22 and 2.23.

Total withdrawals for rural domestic uses are projected to increase 75 percent between 1985 and 2040. New groundwater withdrawals are the source of the increase, tables 2.1, A.5, and A.11 and figures A.13-A.14. Consumption is projected to increase only 12.5 percent over the same period, tables 2.2 and A.17 and figure 2.21. Increasing withdrawals in the face of nearly constant consumption reflects the conversion to pressurized water systems for most rural households by 2040 and the addition of appliances to households where they did not previously exist before.

<u>Potential for Changes in the Projections</u>--As water-conserving appliances make broader inroads into rural construction and home remodeling, the rate of increase in water withdrawals will slow. The water-conserving fixtures were discussed under the municipal section, above. If adoption of these fixtures and appliances proceeds more quickly than recent trends, the rate of increase in withdrawals will slow more quickly than projected.

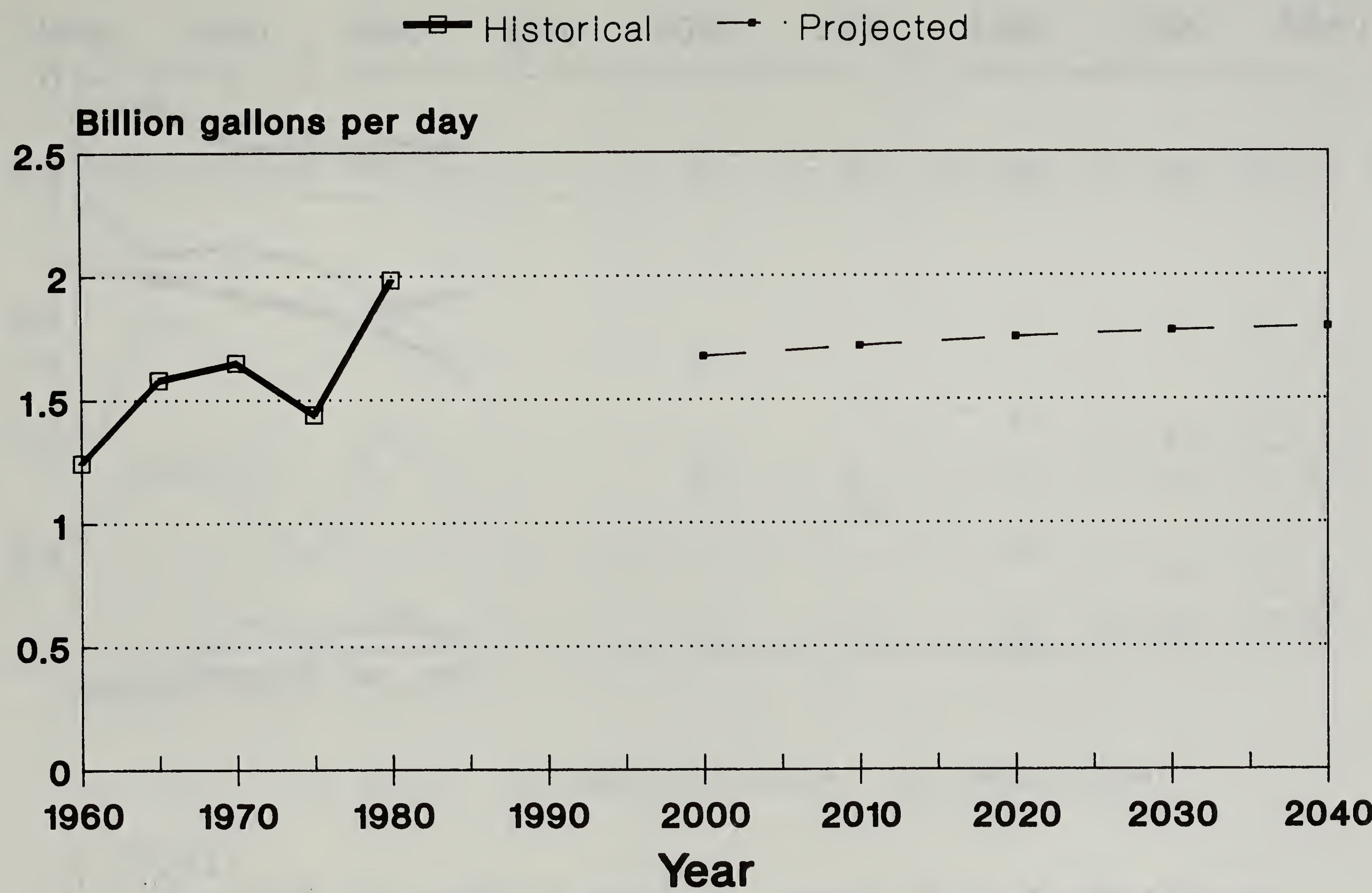
In all areas of the U.S. except the North, a higher percentage of the water supplied to rural households is consumed than is withdrawn. The North has 46.5 percent of domestic self-supplied withdrawals are in the North, but only 28.8 percent of the consumption. The South has 33.9 percent of the withdrawals and 43.7 percent of the consumption; the Rocky Mountains 9.1 percent and 12.6 percent, respectively; the Pacific Coast 10.5 percent and 14.9 percent respectively. Consumption in this context means lost to evapotranspiration or consumed by humans. The North has a cool humid climate, so consumption is lower there because evapotranspiration is lower. Further, the rural areas of

Figure 2.20--Domestic self-supplied water, total freshwater withdrawals



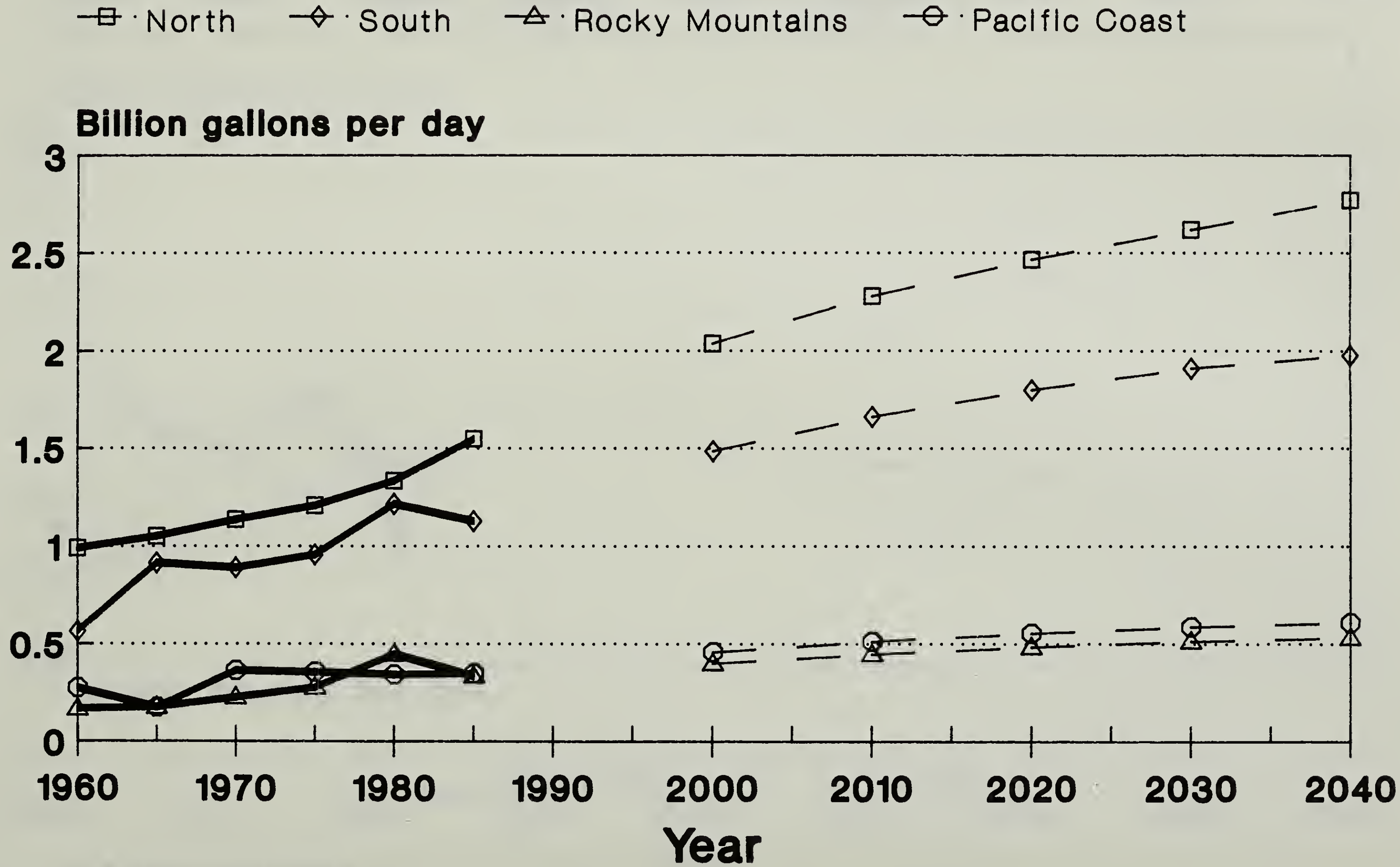
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.21--Domestic self-supplied water, total freshwater consumption



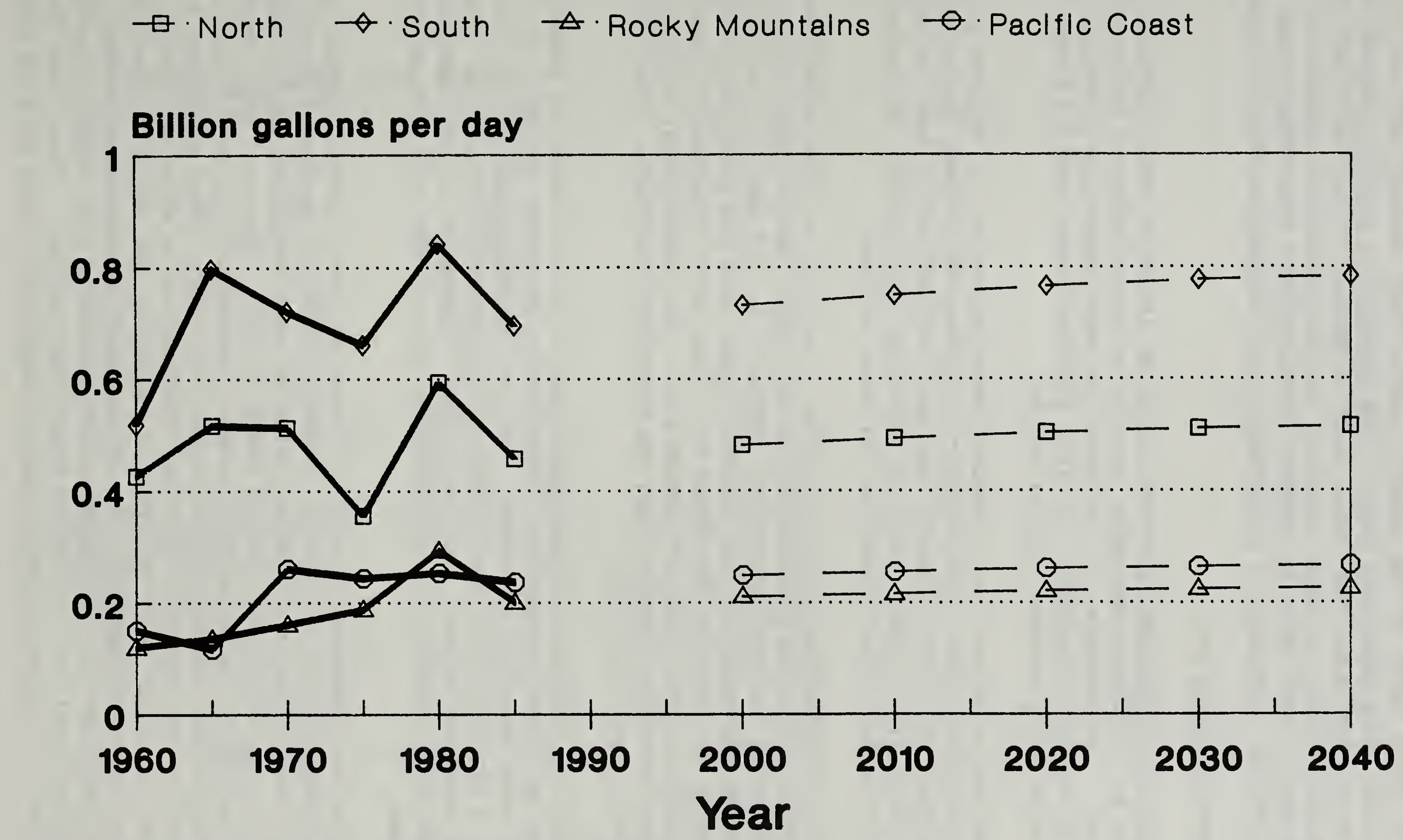
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.22--Domestic self-supplied water, total freshwater withdrawals by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.23--Domestic self-supplies, consumptive use by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

the North are more thickly settled than are the rural areas in the other parts of the country, so a larger percentage of withdrawals occur there. As rural areas in other parts of the country become more densely settled, withdrawals will become more prevalent there. The population shifts underway from the North to the South and West will lead to greater withdrawals and consumption, in absolute terms, in those regions. If the population migration occurs more rapidly and if the "back to nature" out-migration from urban areas increases, the projected increases in withdrawals and consumption will be greater.

Livestock Watering Use

Description of the Use--Livestock watering includes water provided for drinking by livestock and water used to maintain sanitary living conditions for livestock. For example, it includes the water pumped by windmills to stock ponds on western rangeland. It also includes water used to flush manure from dairy barns into a waste holding lagoon.

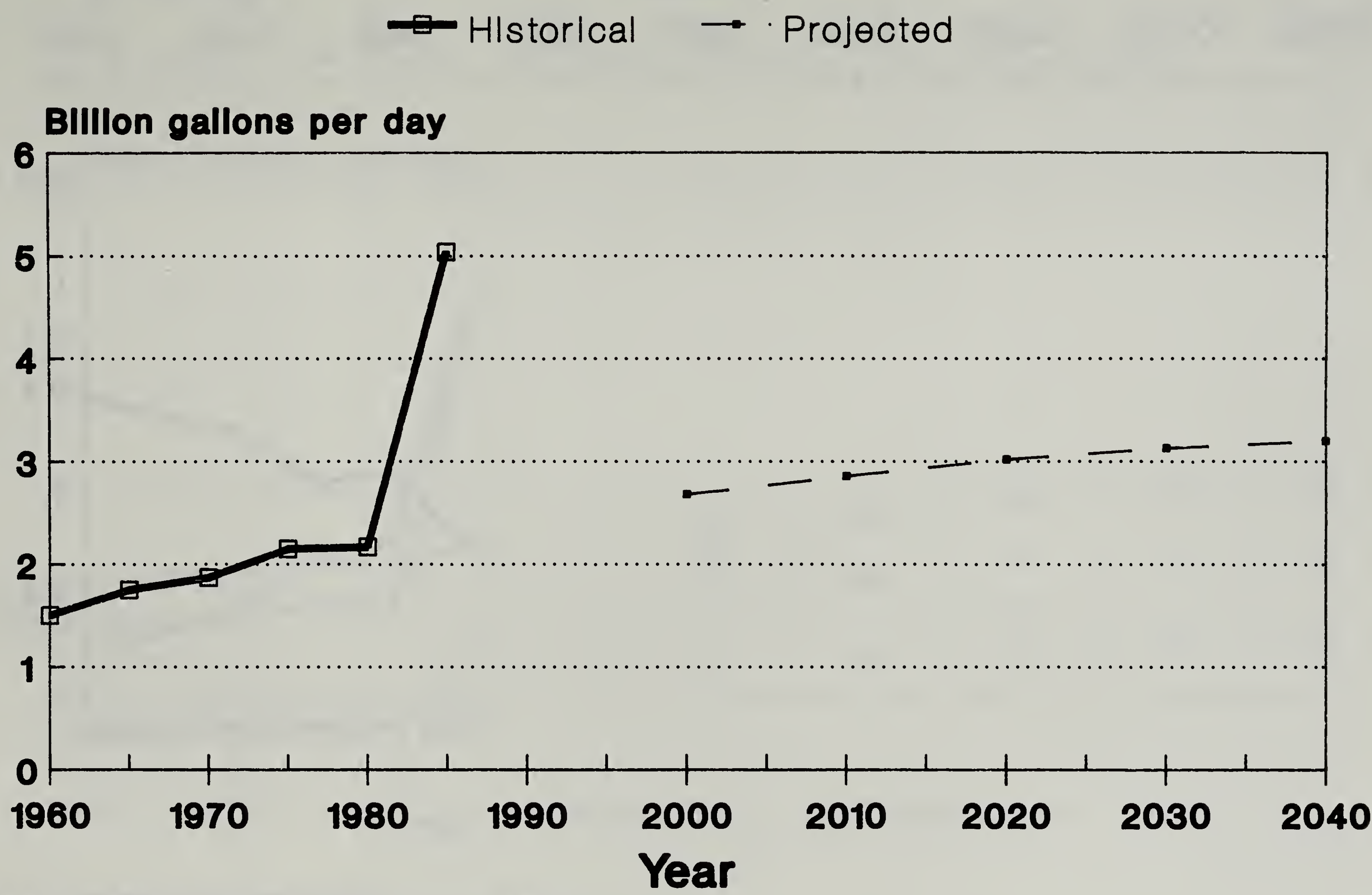
The heaviest water use for livestock watering occurs in regions with high livestock populations. The Missouri, Arkansas-White-Red, Texas-Gulf, Upper Mississippi, Ohio, Mid-Atlantic and South Atlantic-Gulf are the water resource regions with the largest livestock watering withdrawals. Red meat production and dairying are major industries in those regions.

Magnitude of Water Use and Trends--The livestock watering withdrawals and consumption estimates provided by Solley (1987) are substantially different than estimates for previous years, tables 2.1, A.6 and A.12 and figure 2.24. They are on the order of 250 percent higher than the previous years. Consumption in 1985, on the other hand, was only 20 percent higher than in 1980, table 2.3 and A.18 and figure 2.25. The consumption estimate fits the long-term trend much better than the withdrawal estimate. Regional trends are shown on figures 2.26-2.27.

Potential for Changes in the Projections--Livestock watering needs are a function of animal populations, which are a function, in turn, of the demand for red meat and dairy products. The basic assumptions for this Assessment include a projection of beef demand at 80 pounds per capita per year--a demand assumed constant between 2000 and 2040.[4] Consequently, red meat demand for red meat and dairy products is projected to grow at the same rate as population increases.

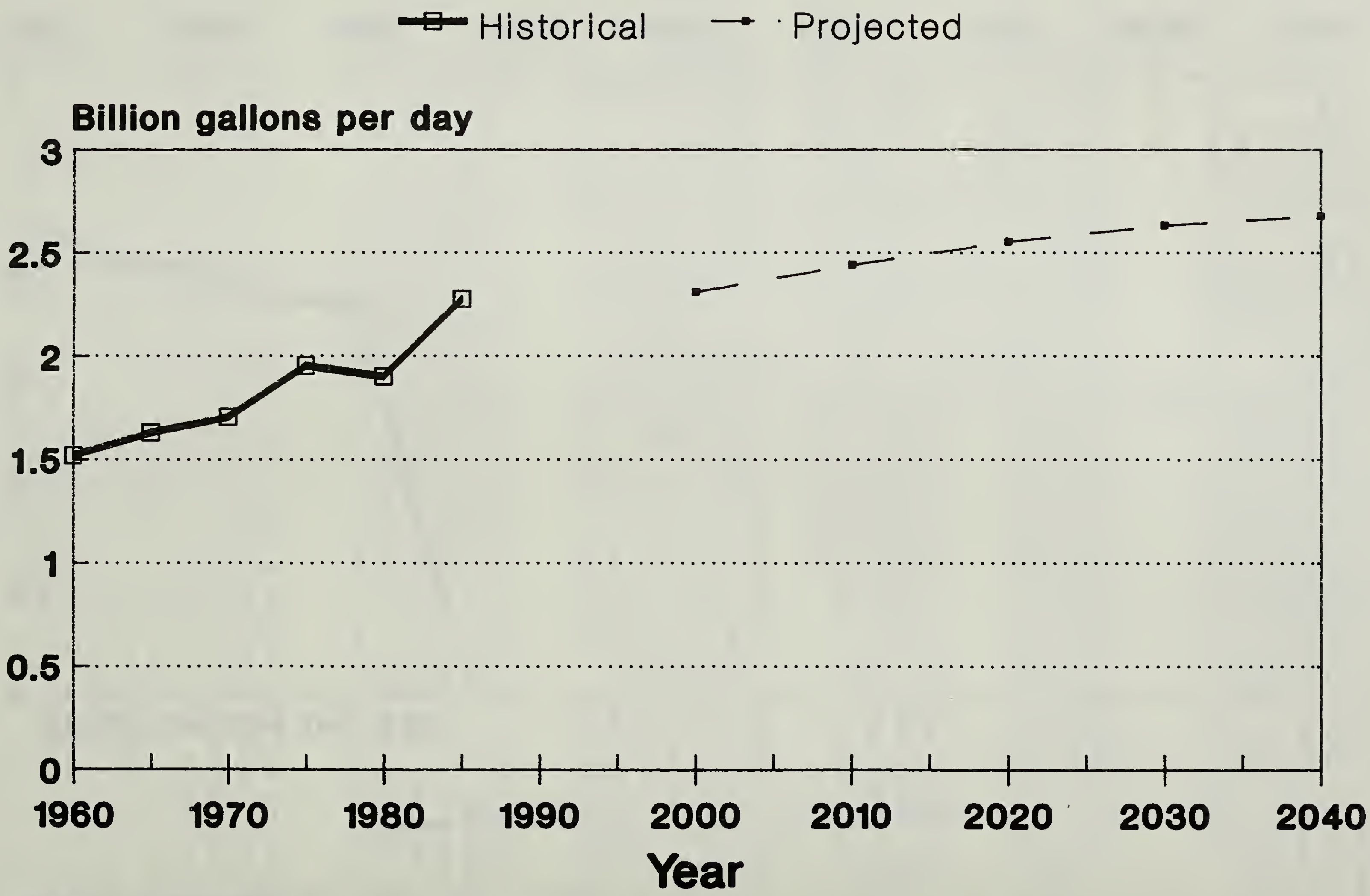
Since the last Assessment in 1979, there has been a marked change in the per capita consumption of red meat. Recent scientific studies linking diet to coronary heart disease and other maladies have concluded that animal fat plays a role in increasing the risk of heart attack. Consumers have responded to these findings by reducing their annual consumption of beef and pork and increasing their consumption of poultry and fish. Beef producers have responded to the change in consumer preferences by altering cattle production practices to reduce beef fat content--reducing the length of feedlot stays and boosting forage consumption. It is too early to determine whether or not red meat consumption will recapture market share and rise back to previous annual consumption levels of 110 to 120 pounds per capita. If so, then the cattle population will increase and livestock water use levels will be affected.

Figure 2.24--Livestock watering, total freshwater withdrawals



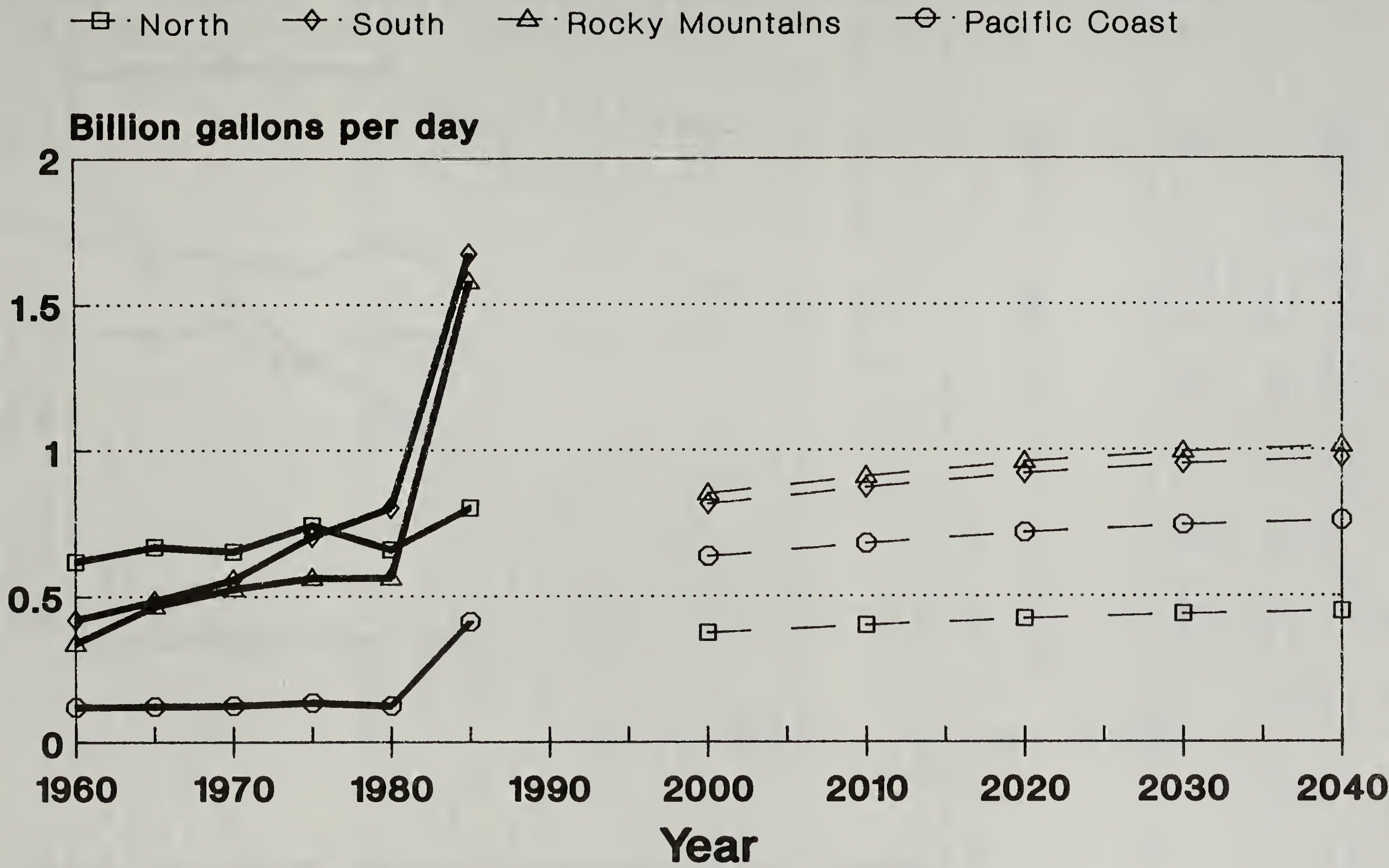
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.25--Livestock watering, total freshwater consumption



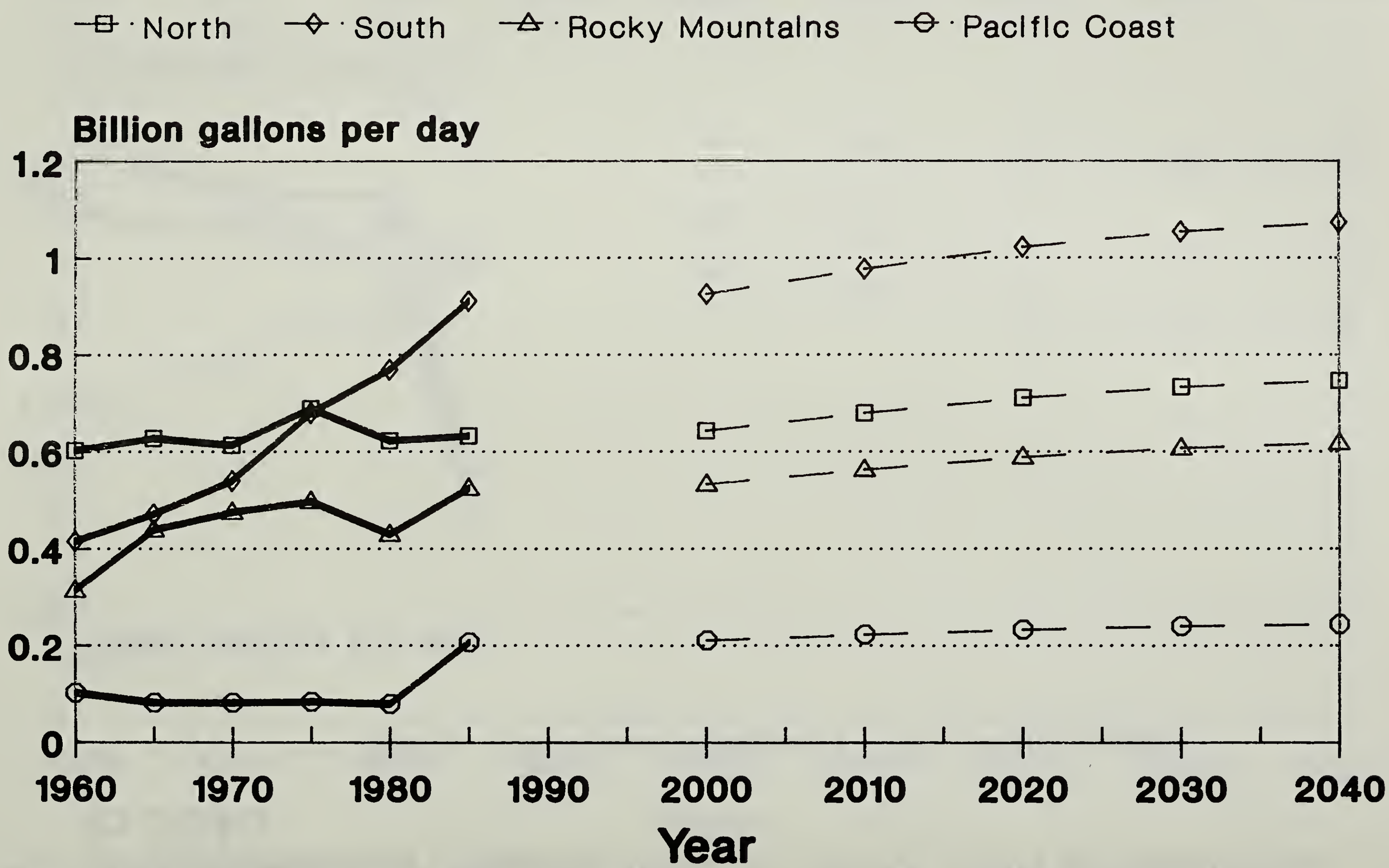
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.26--Livestock watering, total freshwater withdrawals by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure 2.27--Livestock watering, consumptive use by region, 1960 to 1985, with projections to 2040



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

A significant portion of the red meat consumed in the U.S. today is imported from other countries. Abattoirs in Argentina and Uruguay, for example, ship significant quantities of processed beef to the U.S. So even if consumer preferences change and beef consumption increases, domestic producers may not capture the full increment of the consumption increase. Imports may capture a portion of the increase. The share of the increase captured by imports will directly reduce the livestock water consumption otherwise anticipated by increased beef consumption. Similarly, the increase in beef production occurring strictly from increases in the population will not be fully felt in livestock water consumption because of the share of beef imported. Joyce (1988) discusses the relationship of beef imports to demand for red meat in further detail.

Comparison Among Previous Projections[5]

Forecasts of water use have been made over the past three decades by many agencies and commissions. Notable examples are studies by the Senate Select Committee on National Water Resources (U.S. Congress 1961), Wollman and Bonem (1971) in a Resources for the Future publication, The National Water Commission (1973) and the Water Resources Council (1978).

When the Second National Water Assessment (Water Resources Council 1978) was released, there was much discussion about its projections because they deviated significantly from the projections made by the Senate Select Committee (SSC), the National Water Commission (NWC) and Wollman and Bonem (RFF). Viessman and DeMoncada (1980) presented a comparison of withdrawal and consumption projections to the year 2000 from SSC, RFF, NWC and WRC. They noted that all these projections have underlying assumptions. For the most part, population, economic activity and technologic factors were the important factors determining projected water use levels. They also pointed out that projections such as those in the cited studies are only intended to guide decisionmaking and are not to be accepted as "hard" forecasts of the future. The same point was made earlier in this chapter for the projections presented here. The purpose of this section is to review the previous projections and compare them to the ones made here, in light of the withdrawal and consumption data gathered by the Geological Survey since the previous studies. The year 2000 will be used as the year for making comparisons because it is a year common to all the projections.

Senate Select Committee on National Water Resources

The SSC estimated that total freshwater withdrawals in 2000 would reach 888.4 bgd. This was about 2.5 times total withdrawals in 1975. Consumption in 2000 was projected as 156 bgd, an increase of 162 percent over the 1975 level. A medium level population projection of the 48 contiguous states was used--244 million in 1980 and 329 million in 2000. Other assumptions were: the economy would grow at the same rate as in the past; adequate water supplies would be available under prevailing general pricing policies; industrial water use would grow at a high rate; and with the exception of improved irrigation efficiency, existing inefficient methods of water use would continue.

Projections by Wollman and Bonem

The RFF study of water use was an outgrowth of work done by the SSC. Projections were made for 1980, 2000, and 2020 based upon assumptions of high, medium, and low rates of economic growth. Wollman and Bonem states that their findings were not predictions, nor even full-scale projections. Rather, they were an attempt to portray the problem likely to be encountered if current trends continue. The estimates of withdrawals and consumption were based on projected patterns of population and economic activity in conjunction with appropriate water use coefficients. Population projections for 1980, 2000, and 2020 were used as the basis for projecting levels of water use in the U.S. Population projections were used to estimate municipal water use and waste, waste collection costs, rural domestic requirements and to update projections of the food processing industry. It was assumed that regional economic activity would grow or decline relative to growth of the national economy at rates consistent with trends at that time. Estimates of GNP and other indices were used to arrive at projections of other industrial water uses. The net result was that withdrawals were projected to be 563 bgd under the medium growth scenario and 1128 under the high growth scenario. Consumption was projected to be 148 and 190 bgd for the medium and high scenarios, respectively.

The National Water Commission Projections

In its 1973 report on Water Policies for the Future, the NWC commented that its variables in policy and technology combined with hard-to-forecast growth rates in population and economy tend to cast doubts on projections of future water needs based only on past trends. So they devised a variety of alternative futures in which the factors affecting water use were explicitly considered. The NWC analysis incorporated four levels of population and a variety of assumptions about water demand and supply variables. The result was a set of three trends in withdrawals and consumption. Withdrawals were 1510, 1000, and 490 bgd for the high, medium, and low trend scenarios, respectively. Consumption projections were 185 and 125 bgd for the high and low trends, respectively.

Compared to other projections, the NWC high scenario is by far the largest. The assumptions inherent in this scenario called for no change in industrial self-supplied and thermoelectric steam cooling withdrawals, and in particular, a continuation of once-through cooling with no limitations on temperatures of wasteflows discharged to streams. The NWC report acknowledged that substantial reductions in withdrawals would result from adoption of advanced cooling technologies. The other scenarios use this cooling technology to varying degrees.

Second National Water Assessment

The WRC water use projections called for withdrawals of 306 bgd and consumption of 135 bgd by the year 2000. The amount of water withdrawn for manufacturing is projected to decrease by about 60 percent, accompanied by an increase of 137 percent in consumption. Withdrawals for power generation are anticipated to decrease by about 24 percent due to conversion from once-through cooling to

cooling towers. This decline is expected to be accompanied by a substantial increase (600 percent) in the amount of water consumed. But because consumption was less than half a percent with once-through cooling, an increase of the size contemplated would still leave consumption below 3 percent of total withdrawals. The first national water assessment conduced by the WRC was released in 1968. Withdrawals were projected to be 804 bgd and consumption 128 bgd in the year 2000.

In a study of national water supply problems the General Accounting Office (GAO)(1977) questioned WRC's assumptions on industrial water withdrawals because the stringent assumptions of the Clean Water Act may be modified. Further, GAO believed that industries may find it cheaper to continue using water on a once-through basis with wastewater treatment than to construct more costly recycling facilities.

The WRC also projected that irrigation water withdrawals are expected to decline about 8 percent by the year 2000 because of increasing depletions of deep groundwater in southwestern regions. Consumptive use in that sector was also expected to increase less than 2 percent because of water use conflicts and the likelihood that no new large-scale irrigation projects will be publicly funded. GAO challenged these premises also, citing the facts from more northerly regions that water and agricultural conditions were suitable for increases in irrigation in the Missouri and Souris-Red-Rainy water resource regions. They also challenged the WRC assumptions that slower growth in food and fiber requirements and no new large-scale irrigation projects would come to pass.

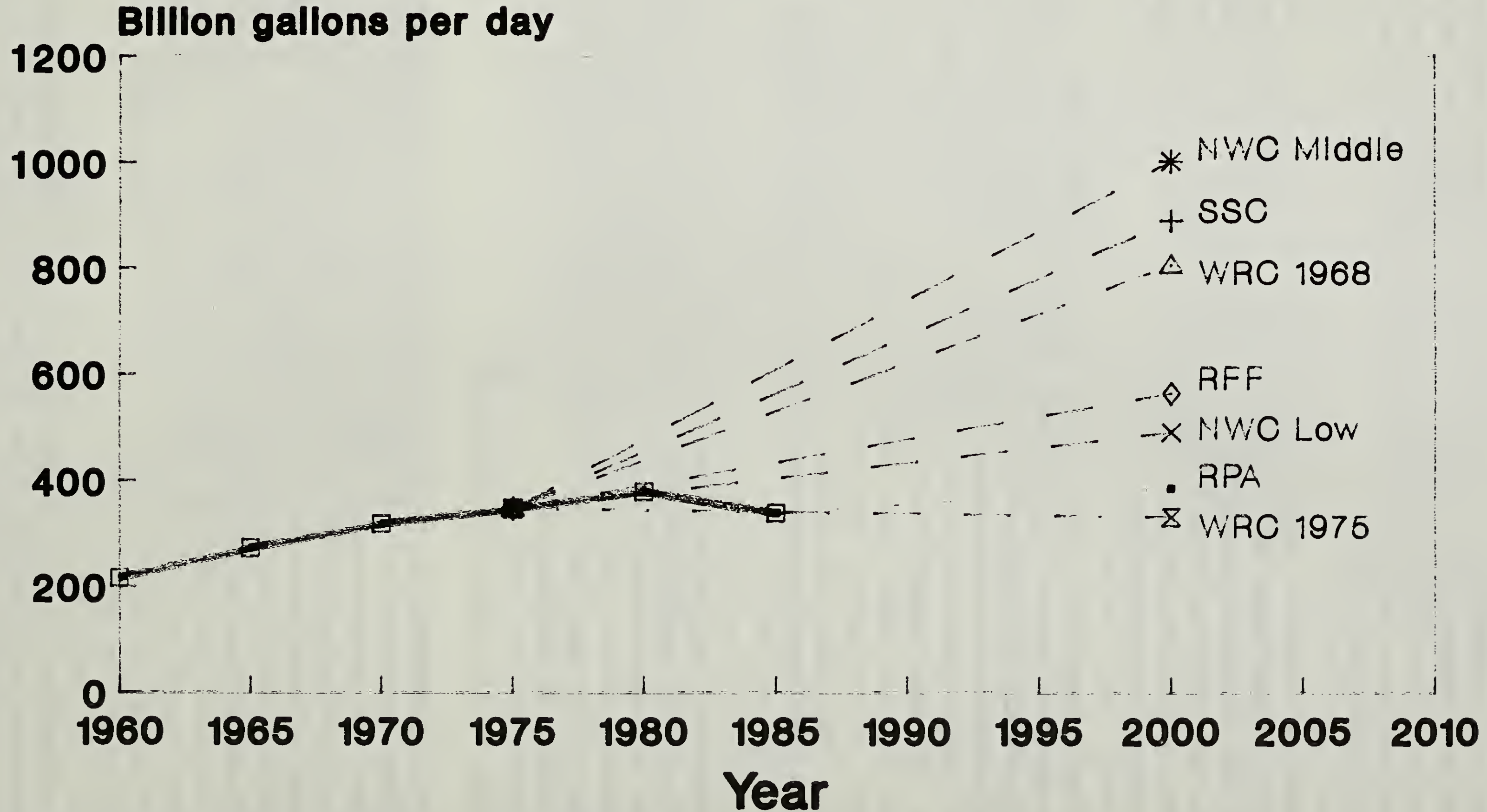
The second national water asessment concluded that many changes had occurred since its first report in 1968. It was noted that population had not grown at the rate anticipated in the previous assessment and that greater awareness of environmental values, water quality, groundwater overdrafts, limitations of available water supplies and energy concerns were having a pronounced impact on water resources management.

Comparison of the Demand Projections

Historical freshwater withdrawals and consumption are plotted along with the projections from various sources in figures 2.28 and 2.29, reproducing figures 55 and 56 from Viessman and DeMoncada (1980). The historical data in their report only extended to 1975. The data for 1980 and 1985 are also plotted on the charge. These more recent data clearly show that withdrawals and consumption trends have followed the WRC 1978 water projections. Analysis of the WRC assumptions reveals that in the past decade, many of them have been upheld--more so than the GAO report believed. The result appears to be a major structural change in the long-term trends for withdrawals and consumption, stemming largely from changes in national water resource policies due to legislation of the early 1970s.

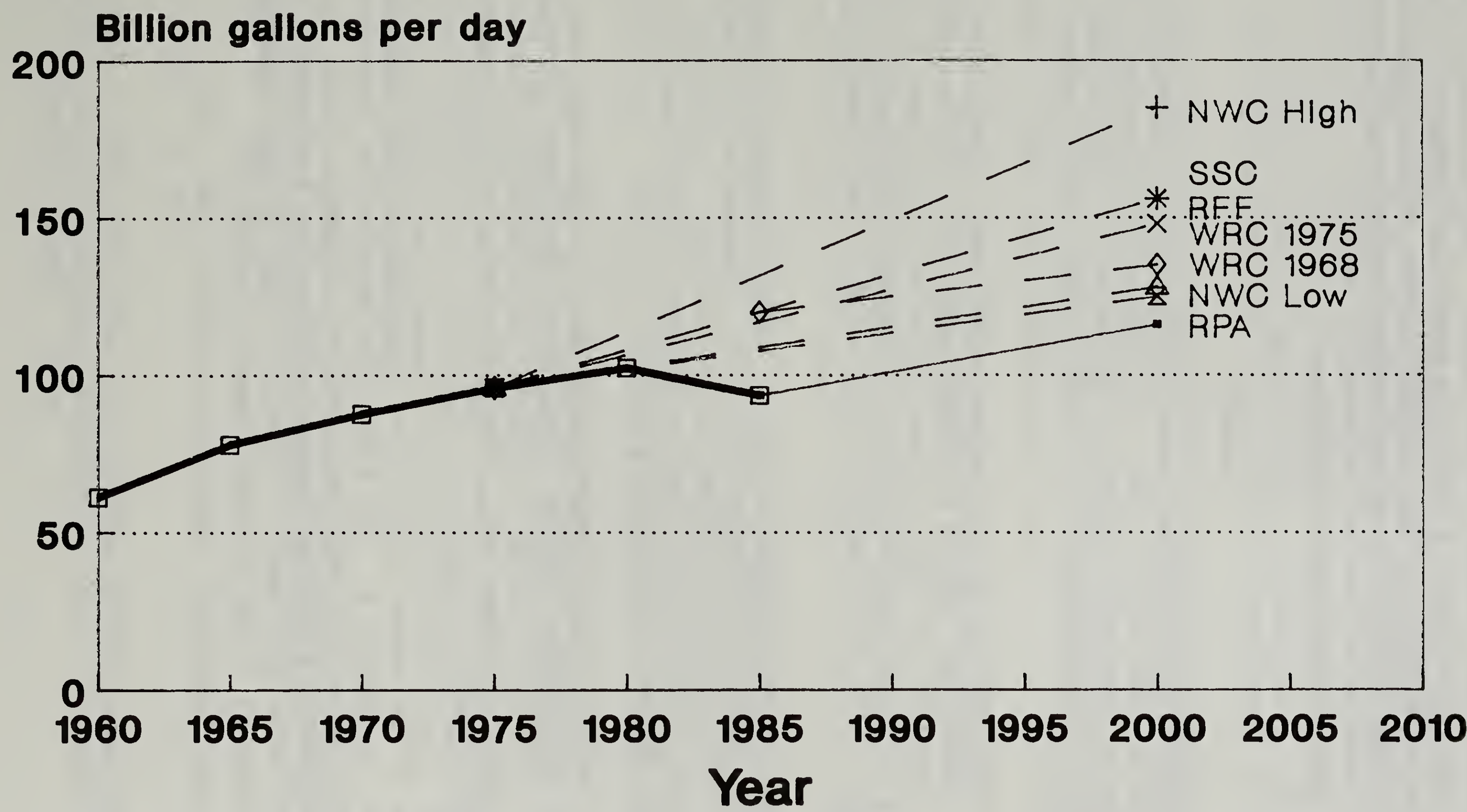
Osborn and others (1986) studied the SSC and WRC projections from the first national water assessment. They compared the projections of water use with estimates of actual use in 1980 to assess the accuracy of water use forecasts. They concluded that water use projections must be based upon methods that help

Figure 2.28--Freshwater withdrawals, 1960 to 1985, with projections from other studies to the year 2000



SOURCE: Historical number from USGS Circulars. See text for projections.

Figure 2.29--Freshwater consumption, 1960 to 1985, with projections from other studies to the year 2000



SOURCE: Historical numbers from USGS Circulars. See text for projections.

explain the effects of water demand determinants on use. Further, they concluded that a detailed analysis of factors that have influenced recent trends in withdrawals and consumption was needed. Recent federal planning guidance (Water Resources Council 1983) has paralleled these findings, calling for specification of factors underlying historically observed patterns of water use and requiring the application of statistical techniques to estimate the relationships between water use and explanatory variables. The demand analyses in this report have followed those guidelines.

Summary

Total demand measured by withdrawals amounted to 343 bgd in 1985 and is projected to rise to 526.6 bgd in 2040. Surface sources provided 75 percent of withdrawals in 1985; projected to rise to 78 percent in 2040. Total demand measured by consumption amounted to 93.6 bgd in 1985 and is projected to rise to 143.1 bgd in 2040.

Thermoelectric steam cooling is the largest withdrawal use of water today and is projected to remain the largest withdrawal use out to 2040. Withdrawals for cooling in 1985 totaled 130.8 bgd and are projected to increase to 228.3 bgd in 2040, due mainly to the projected increase in electricity needed by an expanding economy. Coal will remain the predominant fuel throughout the projection period.

Irrigation is the largest consumptive use of water today and is projected to remain the largest consumptive use out to 2040. Consumption by irrigation in 1985 totaled 73.3 bgd and is projected to rise to 100.1 bgd by 2040. The largest demands for irrigation will be in the Rocky Mountains and Pacific Northwest and the fastest growth in the North.

The demands projected in this Assessment for the year 2000 are lower than the levels projected in previous studies. But recent demand data indicate that there has been a structural change in demand due to pollution control requirements of the Clean Water Act. The projections in this report account for the structural change.

The implications of the demand projections presented in this chapter will be discussed further in Chapter 5. But first, the quantity of water available for use--water supply projections--must be presented (Chapter 3) and the comparisons made between projected demands and supplies to identify regions and time-frames where water shortages are likely to occur if water resource management continues as it has in recent years (Chapter 4).

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Notes

1. Survey procedures in the first two studies (MacKinchan 1951 and 1957) focused on withdrawals. Very little data on consumption was provided. MacKinchan and Kammerer (1961) provided the first estimates of consumption by use and by State. Because water that is withdrawn but not consumed is returned to streams after use, it is available for subsequent withdrawals downstream. Water that is consumed, on the other hand, is not available for withdrawal and use downstream. Hence, consumption data is the more limiting for estimating demand. So our analyses begin with 1960 data, the first year specific consumption data is available.

2. Electrical generating capacity in the U.S. could be increased 15 percent without building any new power plants and the cost of operating generators could be cut 60 percent if the newly invented "high temperature" superconducting materials can be made practical (Rensberger 1988). These estimates were made by researchers at the Argonne National Laboratory in collaboration with five other major energy research centers.

3. The difference between the 105 gpd figure cited here and the 184 gpd figure cited in the municipal self-supplied section is that the 184 figure included the total volume of water supplied by central systems to commercial and industrial establishments and for public uses.

4. Veal and lamb, the two other components of red meat demand, are projected at a constant 4 pound per capita per year over the projection period. Pork consumption is also projected to remain constant at 60 pounds per capita annually. See Darr (1987) for additional details.

5. Information about historical studies in this section of the report is drawn largely from Viessman and DeMoncada (1980). Data for 1980 and 1985 come from Solley and others (1983) and Solley (1987).

Chapter 3

THE SUPPLY SITUATION FOR WATER

The supply of water has two components--quantity and quality. The focus of this chapter is on projecting the supply of water and related land resources to 2040. This chapter begins with a discussion of the quantity aspects of supply and quantity projections over time. The effects of irregular occurrences of oversupply--floods--and their effects on land and developments are reviewed. A Discussion of the projected water quality of the supply follows. The chapter concludes with an overview of the trends in the supply of wetlands. The supply of wetlands is related both to water supply and water quality trends.

Water Supply Quantity

Analysis of the supply of water is different from the analysis of the supply of other renewable resources. For timber, forage, outdoor recreation and wilderness, and for wildlife and fish, managers can take steps to increase the quantity of the resource available for use in the long run. For water and minerals, on the other hand, supplies are essentially constant in the long run. Minerals are a "stock" resource[1] which, for all practical purposes, cannot be renewed in the period covered by this Assessment. Water, on the other hand, is a renewable resource in the sense that rain falls each year to replenish surface water and groundwater. Yet, there is little that water managers can do to influence the quantity of rain that falls in a given year[2]. So, in a sense, the supply of water is a hybrid--a renewable resource because rain falls each year and a stock resource because the quantity of precipitation expected each year is the long-term average, incapable of being altered significantly over wide areas by managers.

In Chapter 1, the current resource situation for water was discussed. A generalized water budget was presented that accounted for groundwater depletion rates and instream flows necessary for optimum wildlife and fish habitat, table 1.2. The generalized budget was developed based on the supply expected in a year of average precipitation--the annual precipitation expected to be exceeded 50 percent of the time. In drier years, less precipitation is expected. For comparison, two additional supply scenarios are presented, table 3.1. The 80 percent level presents the supply expected when the annual precipitation received is expected to be exceeded 80 percent of the time. The 95 percent level presents the supply expected when the annual precipitation received is exceeded 95 percent of the time. Annual precipitation rates lower than the 80-percent level can be expected to occur 2 years in 10; annual precipitation rates lower than the 95-percent level can be expected 1 year in 20. So the 80-percent and 95-percent precipitation levels represent droughts of two different severities.

Table 3.1--Expected annual stream outflows resulting from variations in precipitation levels and instream flow requirements, by water resource region

Water resource region	Annual precipitation quantity expectation[1]			Instream Flow Requirement[2]	
	Mean[3]	80 percent[4]	95 percent[4]	Mean	Dry
	- - - - - - bgd - - - - - -				
New England	76.8	61.4	46.8	69.0	46.1
Mid-Atlantic	93.9	72.3	57.3	68.8	56.3
South Atlantic-Gulf	207.5	147.3	110.0	188.7	124.5
Great Lakes	73.9	57.6	45.1	63.9	44.3
Ohio[5]	137.7	108.9	79.9	122.0	82.6
Tennessee	42.9	37.3	32.6	38.5	25.7
Upper Mississippi[6]	79.8	59.8	42.3	69.7	47.9
Lower Mississippi[7]	463.7	301.4	213.3	359.0	278.2
Souris-Red-Rainy	7.2	4.0	2.2	3.7	2.2
Missouri	51.7	34.6	20.2	34.0	15.5
Arkansas-White-Red	57.2	33.7	19.4	46.2	17.2
Texas-Gulf	31.2	13.4	6.9	22.9	9.4
Rio Grande	2.2	.6	.4	2.3	0.7
Upper Colorado	7.9	5.5	3.1	8.0	2.4
Lower Colorado[8]	1.6	1.4	1.2	6.9	0.5
Great Basin	4.6	2.8	2.1	3.4	1.4
Pacific Northwest	279.8	232.2	195.9	214.0	169.7
California	69.4	43.0	28.4	32.6	20.8
Alaska	921.0	801.3	709.2	797.3	553.6
Hawaii	13.6	9.9	7.6	11.8	8.2
Caribbean	4.8	3.3	1.5	4.2	2.9

1 The mean precipitation level is expected to be exceeded 5 years in 10; the 80 percent level, 8 years of 10; and the 95 percent level, 19 years of 20.

2 The instream flow requirements for the mean precipitation expectation provide optimal fish and wildlife habitat (Water Resources Council 1978). Instream flow requirements for good survival habitat in dry years are assumed to be 60 percent of mean natural flow from the mean precipitation level for the New England, Mid-Atlantic, South Atlantic-Gulf, Great Lakes, Ohio, Tennessee, Upper and Lower Mississippi, Pacific Northwest Alaska, Hawaii, and Caribbean regions. In the other regions, the instream flow requirements for good survival habitat in dry years are assumed to be 30 percent of mean natural flow from the mean precipitation level (Tennant 1975 and Flickinger 1987).

3 Mean annual streamflows for the year of average precipitation are from Foxworthy and Moody (1986, table 7).

4 Mean annual streamflows for the 80-percent and 95-percent precipitation expectations were estimated by computing the percentage reductions in supply presented in U.S. Forest Service (1981, table 7.10) and applying those to the mean flow rates from Foxworthy and Moody.

5 The Ohio region estimates exclude outflows from the Tennessee region.

6 The Upper Mississippi region estimates exclude outflows from the Missouri region.

7 The Lower Mississippi regions estimates represent conditions in all the upstream regions (Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red regions.

8 The estimates for the Lower Colorado region represent conditions in both the Upper and Lower Colorado regions.

SOURCE: After U.S. Forest Service (1981, table 7.10)

Adequacy of Instream Flow[3]

Optimal Habitat--Sixty percent of average flow is the base flow recommended to provide excellent to outstanding habitat for most aquatic life forms during their primary periods of growth and for the majority of recreation uses (Tennant 1975). Channel widths, depths, and velocities at this base flow will provide excellent aquatic habitat. Most of the normal channel substrate will be covered with water, including most shallow riffle and shoal areas. Side channels that normally carry water will have adequate flows. Few gravel bars will be exposed, and the majority of islands will serve as wildlife nesting, denning, nursery, and refuge habitat. The majority of stream banks will provide cover for fish and save denning areas for wildlife. Pools, runs, and riffles will be adequately covered with water and provide excellent feeding and nursery habitat for fishes. Riparian vegetation will have sufficient water. Fish migration is no problem in any riffle areas. Water temperatures should be adequate for fish. Invertebrate life forms should be varied and abundant. Water quality and quantity should be suitable for fishing and floating canoes, rafts, and larger boats, and general recreation. Excellent to outstanding stream esthetics and natural beauty will be maintained.

Good Survival Habitat--Thirty percent of the average flow is a base low recommended to sustain good survival habitat for most aquatic life forms (Tennant 1975). At this base flow level, channel widths, depths, and velocities will generally be satisfactory. The majority of the substrate will be covered with water, except for very wide, shallow riffle or shoal areas. Most side channels will carry some water. Most gravel bars will be partially covered with water and many islands will provide wildlife nesting, denning, nursery, and refuge habitat. Stream banks usually will be sufficient to provide cover for fish and wildlife denning habitat. Many runs and most pools will be deep enough to serve as cover for fishes. Riparian vegetation will not suffer from lack of water. Large fish can move over most riffle areas. Water temperatures are not expected to become limiting in most stream segments. Invertebrate life is reduced but not expected to become a limiting factor to fish production. Water quality and quantity should be good for fishing, floating, and general recreation, especially with canoes, rubber rafts, and smaller, shallow draft boats. Stream esthetics and natural beauty will generally be satisfactory.

Poor Survival Habitat--Tennant (1975) also described conditions for 10 percent of average flow. This flow rate is the minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic life forms. Channel widths, depths, and velocities will all be significantly reduced and the aquatic habitat degraded. The stream substrate or wetted perimeter may be about half exposed, except in wide, shallow riffle or shoal areas where exposure could be higher. Side channels will be severely or totally dewatered. Gravel bars will be substantially dewatered and islands will usually no longer function as wildlife nesting, denning, nursery, and refuge habitat. Stream bank cover for fish and fur animal denning habitat will be severely diminished. Many wetted areas will be so shallow they no longer will serve as cover, and fish will generally be crowded into the deepest pools. Riparian vegetation may suffer from lack of water. Large fish will have difficulty migrating upstream over many riffle areas. Water temperature often becomes a limiting factor,

especially in the lower reaches of streams in July and August. invertebrate life will be severely reduced. Fishing will often be very good in the deeper pools and runs because fish will be concentrated. Many fishermen prefer this level of flow. However, fish may be vulnerable to over harvest. Floating is difficult even in a canoe or rubber raft. Natural beauty and stream esthetics are badly degraded. Most streams carry less than 10 percent of the average flow at times. From this description, it is plain that if streamflows less than 10 percent of the mean annual streamflow occur for several weeks, this low flow rate will usually have serious adverse effects on aquatic habitat.

<u>Instream Flow Rates and Regional Water Balances</u>--When the instream flow requirements for optimal habitat (from Water Resources Council 1978) and good survival habitat (from Tennant 1975 and Flickinger 1987) are compared with the instream flows based upon precipitation expectations, table 3.1, several points are worth noting. First, even with the mean expectation of precipitation, the Rio Grande, Upper and Lower Colorado, and Great Basin areas will not have enough water instream to meet optimal habitat requirements. Second, and a counterpoint to the point just made, only the Texas-Gulf and Rio Grande of the western regions cannot provide good survival habitat in drought years. So although the habitat is not optimum, the flows in dry years in the western regions nevertheless provide good habitat for survival. Only in the Rio Grande water resource region will the dry-year precipitation at less than the 80-percent level not provide satisfactory survival habitat. Third, in the mean year, flows in the eastern water resource regions provide optimal fish and wildlife habitat. Even in the 80-percent year, flows are significantly greater than the minimums necessary for good survival habitat. Fourth, the precipitation expected 1 year in 20 will result in flows less than those necessary for good survival habitat in the South Atlantic-Gulf, Ohio, Upper and Lower Mississippi, Texas-Gulf, Rio Grande, Hawaii, and the Caribbean water resource regions.

To this point, the discussion has focused upon annual precipitation and average flow rates. It is well known, however, that precipitation is not distributed uniformly throughout the year in many parts of the U.S. Thus, there are often periods of time when suboptimum flow rates occur. Many water resource regions have main streams and tributaries whose flows are well below the "good survival habitat" level at some time during the year--even a year of relative abundance of precipitation. Many streams also approach or go below the "minimum short-term survival" flow level.

Daily and seasonal flow variations in streams might not be solely a function of precipitation patterns. Reservoir releases are a prime cause of flow variations. There are four major uses of water in streams that are served by reservoirs--flood control, irrigation, navigation, and generation of electric power. The first example to illustrate the effect of reservoir releases is the data in table 3.1 for the western regions. Of the western regions, only the Texas-Gulf and Rio Grande regions cannot provide good survival habitat when precipitation falls to the 95-percent level (more precipitation expected in 19 of 20 years). Because of poor seasonal distribution of precipitation for forage and crop production--much coming as snow--reservoirs were constructed to capture springtime runoff (flood control and irrigation the main purposes). The tabular data show that instream flows are rarely optimal but also rarely

less than levels providing good survival habitat. In contrast to the western irrigation and flood control reservoirs, the dams built on the Mississippi and Ohio Rivers to enhance navigation do not appear capable of maintaining good survival habitat in exceptionally dry years. Navigation releases are a function of barge traffic. To assure sufficient flows for commercial needs in dry years, little water may be passed when barges are not using the locks. Hydroelectric releases are a function of electricity needs. Hydropower reservoir discharges vary widely during the day in response to the changing demand for electricity. Because of the increased prevalence of air conditioning and the switch to electricity as a preferred energy source in the mid-1970s, peak electricity demands on mid-summer weekday afternoons often result in water releases from hydroelectric facilities that are many times the off-peak release rates. In the mid- and southern Appalachians, reservoir releases for recreation are becoming more prevalent. Whitewater rafting schedules are coordinated among outfitters and reservoir operators, such as the Corps of Engineers, to guarantee quality recreation experiences. High release rates are common on weekend mornings. All these factors contribute to wide daily and even hourly fluctuations in flow rates in rivers--fluctuations that can have negative as well as positive impacts upon wildlife and fish habitat and other instream water uses. In recent years, maintaining adequate wildlife and fish habitat has become an important factor that reservoir operators must consider when planning operations directed primarily at satisfying other needs.

The effect of forests and other vegetation on runoff and streamflows, especially in reducing wide variations in flow, has long been known. Troendle (1983) and Douglas (1983) summarized the state-of-the-art about using vegetation management to influence timing of streamflows. They concluded that timber harvesting patterns and frequencies can be planned to trap snow at high elevations and extend the period of snowmelt into the summer. The result is that high springtime peak flows are reduced. It has also been demonstrated that maintaining vegetation on sites keeps soil infiltration and percolation rates higher than on bare sites. Thus, less runoff occurs and storm flow peaks are reduced. Many suburban areas have adopted zoning regulations in recent years specifying the use of vegetated areas to delay or temporarily store runoff and cut peak storm flows. In more rural settings, managing riparian vegetation accomplishes the same objective. These nonstructural methods are now viewed as realistic alternatives to structural methods, such as dam construction and channelization, for reducing wide swings in streamflows.

Flooding

While the principal question in the foregoing discussion about adequacy of instream flows focused on paucity of water, flooding impacts result from just the opposite. In 1985, despite state-of-the-art communications and weather forecasting models, 44 people were killed by floodwater and property damage totalled more than $366 million (Moody and others 1986, table 1)(not included in these estimates was Hurricane Elena, which also caused "hundreds of millions of dollars" in damage and resulted in the evacuation of a million people). Almost half of all flood damages are to agriculture, as crops and livestock are destroyed and soil is washed away. Two-thirds of the total flood damages occur in rural areas. In urban areas, flood damages destroy homes and places of employment. The Federal Emergency Management Agency (FEMA) has determined that

about 20,000 of the 34,000 communities in the United States have some flood hazard areas (FEMA 1986).

The impact of flooding on wildlife, fish, and ecosystems is mixed. In upstream areas, wildlife food and habitat are often washed away or covered with flood debris causing severe damage to natural systems. Less measurable losses include funds spent for relief and reconstruction, lost productivity and the general disruption of the local and regional economy during and after a flood. However, flooding may transport beneficial nutrients that improve downstream ecosystems. For example, when the Bonnie Carret Spillway on the Mississippi River above New Orleans is opened (a mile-long series of floodgates) to divert floodwater into Lake Pontchartrain, shrimping in the Lake that year is detrimentally impacted due to the silt and the decline in salinity. However, two to three years after a spillway opening, the nutrients brought by the floodwater work their way up in the ecosystem and shrimp populations and sizes soar for a year or two.

Since 1941, annual flood damages in the U.S. have not been less than $50 million. Average annual damages between 1940 and 1970 exceeded $500 million (1984 dollars). Damages have exceeded $5 billion several times since 1970, the highest being $12 billion in 1972 when Hurricane Agnes devastated the Susquehanna River basin. Despite the increasing trend in annual flood damages,[4] there is no evidence that storms are increasing in magnitude or frequency. The increases in damages result from intensified development in flood-prone or flood-susceptible areas (Water Resources Council 1978) and from concentrating higher-valued agricultural production on flood plains (Department of Agriculture 1987).

Average annual flood damage per square mile varies considerably among water resource regions. The wide variation is related partly to weather patterns, partly to the character of the streams in the region, and partly to the average value of streamside property subjected to flooding.

Floods have serious effects on humans outside the flooded area too. Floods overrun sewage treatment facilities which are often located along streams to take advantage of gravity for transporting wastes to the plant. The resulting contamination of floodwater and everything the floodwater touches not only impacts public health in a physical sense, but also in a psychological sense as well. Many of these problems continue long after the floodwater recede. The yearly loss of life from floods has usually been less than 100, but it exceeded 500 in 1972.

Floods can be both devastating or beneficial to agricultural interests. They can wipe out crops and dump tons of sand, gravel, clay, and other debris on productive lands. Floating debris, such as trees and parts of buildings, can cause significant damage to structures such as bridges, culverts and associated roads, and other structures in the floodplain. Loose debris that is carried in floods often forms debris dams when trapped against bridges. These debris dams often cause the floodwater to carve out alternate routes past the flow constriction, eroding abutments and approaches to the bridges or damaging additional structures as a pool forms behind the dam. If the debris dam breaks, such as when a bridge is washed off its supports, the resulting surge

of water and debris can cause additional damage to structures downstream. On the positive side, slow-moving floods can deposit fertile, highly-productive sediments on cropland and wetlands. The infusion of nutrients can boost crop, wildlife, and fish production in subsequent years.

Average annual flood damages are projected to increase to $6.7 billion by the year 2000 (Forest Service 1981)(1987 dollars). Agricultural damages are expected to be more than $2.7 billion in 2000 while urban damages are projected to increase by 36 percent to $2.5 billion. All other damages are expected to average about $1.5 billion. By 2040, total annual damages are projected to reach $9.7 billion. It was not possible to project deaths due to flooding because past annual totals vary widely.

Regional estimates and projections of flood damages are closely correlated with population densities. The highest damages are likely to occur in the South Atlantic-Gulf, California, and Missouri regions. Agricultural damages are most important in the Upper and Lower Mississippi and Missouri regions. But they are also significant in the Ohio, Arkansas-White-Red, Texas-Gulf, Great Basin, CAlifornia, and Pacific Northwest regions. Urban damages will be more prominent in California, New England, Mid-Atlantic, and the Great Lakes regions.

Summary

This analysis of water supply quantity includes no assumptions about consumption of water in offstream uses. That information is presented in Chapter 4 where the supply and demand projections are compared. The quantity of precipitation is a stochastic variable in any given calendar year; consequently, so is streamflow. If precipitation is below normal, the chance of detrimental impact on fish and wildlife habitat and other instream uses increases. If precipitation is above normal, the chance of detrimental impact due to flooding increases. No long-term trends in precipitation have been observed this century; consequently, the quantity of water supplies has no discernable trend. Annual fluctuations are sufficiently large to make water resource management a challenge in spite of the absence of a long-term trend.

Water Supply Quality[5]

The natural quality of water in the Nation's streams and lakes is, in large part, a reflection of the characteristics of the land and vegetation from which the water flows. Because of the natural variation in land and vegetation, the quality of water in streams and lakes is neither uniform nor static. Water is constantly moving, even in lakes and reservoirs; as it moves, its quality changes. It is influenced by natural features, including geology and topography, soil, and vegetation.

The natural quality of water is also affected by the actions of people. These actions include road construction, urban development, farming, mining, timber harvesting, livestock grazing, and discharge of municipal and industrial wastes. Acid deposition also affects natural water quality--both near and far from the point where chemicals are released to the atmosphere.

Water is often used and reused several times and for many purposes during its journey to the sea. Water quality can be either improved or degraded as it is used and returned to a stream. Because it is ever-moving and ever-changing, water quality is difficult to inventory and measure. Without good inventories of water quality over time, making projections is virtually impossible.

It is important to recognize that water quality determines the useability of water for specific purposes. Water quality can be suitable for one purpose, while simultaneously being poor for another use. For example, a clear alpine lake may be excellent for aesthetic enjoyment and trout fishing, but very poor for swimming because the water temperature rarely exceeds 50 F^{o}. Another example would be when natural water quality is ideal for swimming and for fish, wildlife, and livestock consumption, but unsatisfactory for a particular industrial use because of the content of dissolved solids, such as iron.

Baseline Water Quality from Forests and Rangelands

To show the relationship of water quality to its natural environment, relatively undisturbed forest and range land watersheds with available water quality data were selected in each division, province, or section as described by Bailey (1976), table 3.2. Bailey's hierarchical system for land classification (ecoregions) begins with the largest, broadest definition as a domain, and proceeds downward in size and in specificity through division and province to section, the smallest and most discrete unit. Each section describes a more or less continuous geographical area and is characterized by distinctive fauna, climate, landform (including drainage pattern), soil, and vegetation that distinguishes it from adjacent sections. Within such sections, ecological relationships between plants, soil and climate are essentially similar, so similar management treatments give comparable results and have similar effects on the environment. They are considered to be biological and physical areas of specific potential.

In addition to being relatively undisturbed (no major land disturbing activities within at least the last 5 years), the selected watersheds were also small (10 to 200 square miles), more than 90 percent forest or range land or both, and had a minimum of 5 years (10 years when possible) of water quality records that included total dissolved solids, dissolved oxygen, water temperature, and suspended sediment. These data from STORET[6], show how baseline water quality parameters vary by ecoregion, table 3.2. The quality of the water in all of the undisturbed watersheds exceeds the minimum water quality standards of most States. There is, however, a substantial amount of variability in the various measures of quality among the divisions, provinces, and sections.[7]

The baseline water quality levels in table 3.2 represent the best water quality that can be attained from managing forests and rangelands. Thus, maintaining this quality in streams becomes the goal for forest and range managers. Management activities often result in changes in water quality. Some changes are short-term, others are longer-term. Some changes have only a local effect, others are more regional. For example, timber harvesting in the South is usually followed by regeneration the following year. The rapidity with which

Table 3.2--Data for selected numbers of water quality from undistributed forest and range watersheds in the United States, by division, province, and section

Division, province, and section	Total dissolved solids (mg/1)[1] [4] Percentile			Dissolved oxygen (% saturation)[2] Percentile			Water temperature (degrees centigrade) Percentile			Suspended sediment (mg/1)[3] Percentile		
	15	50	85	15	50	85	15	50	85	15	50	85
1300 Subartic												
M1310 Alaska Range	50	90	120	90	95	100	.0	6.0	13.0	1	3	40
											(100)	(500)[5]
1320 Yukon Forest	43	63	80	95	98	100	.0	3.8	7.5	10	20	40[6]
2100 Warm Continental												
2110 Laurentian Mixed Forest												
2111 Spruce-Fir	62	91	120	79	90	104	.0	10.0	15.5	0	4	14
2112 Northern Hardwoods-Fir	68	104	132	77	87	98	.0	8.0	20.0	2	4	10
2113 Northern Hardwoods	25	29	35	89	97	105	.0	8.0	17.0	1	3	8
2114 Northern Hardwoods-Spruce	16	20	25	86	92	100	.0	4.0	19.0	1	2	5
M2110 Columbia Forest												
M2111 Douglas-fir Forest	70	100	150	85	91	97	3.0	4.0	9.0	10	40	60
M2112 Cedar-Hemlock-Douglas-fir	48	52	54	85	95	105	.0	63.0	11.0	2	5	10
2200 Hot Continental												
2210 Eastern Deciduous Forest												
2211 Mixed Mesophytic	14	16	18	87	93	100	4.5	10.0	16.0	2	4	17
2212 Beech-Maple	206	368	556	80	94	100	4.0	10.5	23.0	2	24	95
2213 Maple-Basswood + Oak Savanna	239	294	313	86	96	110	1.0	9.0	17.0	14	48	734
2214 Appalachia Oak	22	25	29	89	97	105	2.0	6.0	15.0			
2215 Oak Hickory	44	62	156	84	94	105	7.0	15.0	23.0	2	8	40
2300 Subtropical												
2310 Outer Coastal Plan Forest												
2311 Beech-Sweetgum-Magnolia-Pine-Oak	16	23	53	73	83	90	10.0	18.0	24.0	4	19	
2312 Southern Flood Plain	16	23	53	73	83	90	10.0	18.0	24.0	4	19	83
2320 Southeastern Mixed Forest	15	22	34	9*	98	105	9.0	16.0	23.0	3	7	20
2400 Marine												
2410 Willamette-Puget Forest	46	62	75	70	80	90	2.0	12.0	18.0	5	10	20
M2410 Pacific Forest	15	40	75	95	98	100	1.0	5.0	9.0	1	3	40
										(20)	(80)	(400)[5]
M2411 Sitka-Spruce-Cedar-Hemlock	34	48	65	92	95	98	4.0	8.0	11.0	1	2	8
M2412 Redwood Forest	52	87	124	95	98	105	7.0	12.1	18.0	3	26	118
M2413 Cedar-Hemlock-Douglas-fir	25	50	90	85	90	95	3.0	9.0	16.0	4	8	12
M2414 California Mixed Evergreen	50	120	150	93	97	99	8.0	14.5	21.2	6	45	175
M2415 Silver Fir-Douglas-fir	23	46	68	85	90	94	1.4	6.2	10.9	2	5	10

See footnotes at end of table.

Table 3.2--Data for selected numbers of water quality from undistributed forest and range watersheds in the United States, by division, province, and section -- continued

Division, province, and section	Total dissolved solids (mg/1)[1] [4] Percentile			Dissolved oxygen (% saturation)[2] Percentile			Water temperature (degrees centigrade) Percentile			Suspended sediment (mg/1)[3] Percentile		
	15	50	85	15	50	85	15	50	85	15	50	85
2500 Prairie												
2510 Prairie Parkland												
2511 Oak-Hickory-Bluestem	235	314	370	76	94	128	.0	13.0	22.0	17	55	214
2512 Oak + Bluestem	51	55	58	--	--	--	11.0	20.0	25.0	--	--	--
2520 Prairie Brushland												
2521 Mesquite-Buffalo Grass	240	270	280	83	94	100	12.0	19.0	26.0	2	8	80
2522 Juniper-Oak-Mesquite	244	278	290	83	94	100	11.5	19.0	25.5	2	8	80
2523 Mesquite-Acacia	250	280	295	82	92	100	12.0	19.0	26.0	2	8	80
2530 Tall-grass Prairie												
2531 Bluestem	352	868	1060	70	86	100	.0	9.0	19.5	24	80	199
2532 Wheatgrass-Bluestem-Needlegrass	149	155	161	79	83	90	4.5	9.5	20.0	448	508	650
2533 Bluestem-Grama	72	104	133	54	81	100	5.0	13.0	23.0	--	--	--
2600 Mediterranean												
2610 California Grassland	400	600	800	90	95	100	8.0	18.0	28.0	30	60	90
M2610 Sierran Forest	11	19	20	90	96	102	6.2	13.8	15.5	1	3	5
M2620 California Chaparral	300	600	800	90	94	98	7.2	17.8	24.1	10	20	30
3100 Steepe												
3110 Great Plains Shortgrass Prairie												
3111 Grama-Needlegrass-Wheatgrass[5]	994	2189	3384	53	70	87	1.4	9.7	18.0	10	6000	16186
3112 Wheatgrass-Needlegrass[7]	235	257	269	70	80	87	.0	4.0	12.0	25	47	81
3113 Grama-Buffalo Grass	1491	1610	1730	80	92	104	4.0	13.0	21.0	118	188	258
M3110 Rocky Mountain Forest												
M3111 Grand Fir-Douglass-fir	32	48	57	87	94	99	1.5	8.0	15.5	1	6	22
M3112 Douglas-fir	25	140	400	76	83	110	.0	6.0	12.0	7	25	300
M3113 Ponderosa Pine-Douglas-fir	38	52	60	65	73	78	.0	4.0	11.0	2	4	9
3120 Palouse Grassland	200	250	300	60	70	80	2.0	10.0	17.0	50	500	5000
M3120 Upper Gila Mountains Forest	63	128	173	73	87	114	6.0	11.0	21.0	1	2	20
3130 Intermountain Sagebrush												
3131 Sagebrush-Wheatgrass	85	109	124	9	11	12	2.0	11.0	24.0	4	9	57
3132 Lahontan Saltbush-Greasewood	50	80	100	74	79	84	1.0	8.0	15.0	13	30	177
3133 Great Basin Sagebrush	70	80	100	73	80	90	1.0	8.0	15.0	2	25	1970
3134 Bonneville Saltbush-Greasewood	1000	1400	3200	70	80	90	2.0	9.0	15.0	10	30	2000
3135 Ponderosa Shrub Forest	55	59	66	75	85	95	1.0	14.0	19.0	5.6	17.5	59.5
P3130 Colorado Plateau												
P3131 Juniper-Pinyon Woodland+ Sagebrush-Saltbush Mosaic	150	225	350	70	82	100	4.0	13.0	21.0	5	25	500
P3132 Grama-Galleta Steepe+ Juniper-Pinyon Woodland	158	228	390	85	95	145	5.0	16.0	23.0	19800	24800	37900

See footnotes at end of table.

Table 3.2--Data for selected numbers of water quality from undistributed forest and range watersheds in the United States, by division, province, and section -- continued

Division, province, and section	Total dissolved solids (mg/1)[1] Percentile[4]			Dissolved oxygen (% saturation)[2] Percentile			Water temperature (degrees centigrade) Percentile			Suspended sediment (mg/1)[3] Percentile		
	15	50	85	15	50	85	15	50	85	15	50	85
3140 Mexican Highlands Shrub	427	915	1180	95	105	105	15.0	25.0	33.0	14200	68940	111000
A3140 Wyoming Basin												
A3141 Wheatgrass-Needlegrass-Sage	220	495	770	78	87	96	2.0	9.0	17.0	78	850	1622
A3142 Sagebrush-Wheatgrass	190	267	344	71	82	93	2.0	9.0	17.0	1	191	565
3200 Desert												
3210 Chihuahuan Desert												
3211 Grama-Tobosa	1900	2450	2990	100	120	130	8.0	18.0	27.0	12	55	86
3212 Tarbush-Creosote Bush	93	114	132	--	--	--	13.0	21.0	25.0	--	--	--
3220 American (Mojave-Colorado-Sonoran)												
3221 Creosote Bush	509	541	603	70	105	140	13.0	21.0	28.0	7	576	1030
3222 Creosote Bush-Bur Sage	600	700	800	60	70	100	13.0	26.0	32.0	1000	5000	200000

[1] All solid material that passes through a filter membrane having pores of 0.45 micron in diameter. Measured in milligrams per liter (mg/1).
[2] The ratio of the amount of dissolved oxygen present in water at a given temperature to the amount of dissolved oxygen water can hold at that temperature, expressed as a percent.
[3] The inorganic particles larger than 0.45 micron in diameter carried in suspension by the water. Measured in milligrams per liter (mg/1).
[4] Percentile figures are determined from an analysis of a frequency distribution. The 50th percentile represents the median (midpoint) of the data and a range is selected in which 70 percent of the data falls between the 15th and 85th percentiles.
[5] Figures in parentheses are for streams with a major contribution from glacial melt and are for the same ecoregions as figures immediately preceding.
[6] Suspended sediment figures for Yukon Forest do not include that measured in the Yukon River which is a glacial melt river originating in Canada.
[7] These figures represent only the Black Hills portion of this ecoregion.

NOTE--Numbers before the division, province, and section designations refer to lowland ecoregions as described in Forest Service, U.S. Department of Agriculture, Ecoregions of the United States, 1976. Letters with the numbers, i.e., M1310, P3131, A3142, etc., indicate highland ecoregions in which M = mountains, P = plateau, and A = altiplano (a high plateau or plain).

Source: Environmental Protection Agency. National Water Quality Data Storage and Retrieval Program (STORET).

vegetation reoccupies the site harvested means that bare soil is rarely exposed for more than three years. Consequently, the harvesting and regeneration operation only imposes a short-term effect upon water quality from site runoff. Timber harvests on southern National Forests average 40 acres in size. Water quality effects from runoff from such a small area will also tend to be localized. Through careful planning and attention to details in implementation, significant long-term adverse water quality effects from land management activities can be avoided or mitigated.

Approaches to Improving Water Quality

The Clean Water Act determines the way the Federal government and States regulate point and nonpoint-source pollution. Although amended in 1977, 1981, and 1987, the basic directives embodied in the original Act continue to guide the Nation's water pollution control programs.

Point Sources--Two types of approaches were established by the Act for controlling pollution from point sources: the technology-based approach, and the water-quality based approach. Technology-based controls consist of uniform EPA-established standards of treatment that apply to industries and municipal sewage treatment facilities. These effluent standards are limits on the amounts of pollutants that may be discharged to streams. The limits are derived from the technologies that are available for treating wastewater and removing pollutants. They are applied uniformly to every facility in an industrial category, such as the pulp and paper industry, regardless of the condition of the stream to which the effluent is discharged.

Water quality-based controls, on the other hand, are based upon the quality of the water in the stream receiving the effluent. This approach relies on the use of water quality standards set by the States on the basis of the uses to be made of the streams (e.g. fishing and swimming) and the criteria (or limits on pollutants) necessary to protect those uses. Individual discharge requirements are based on the effluent quality that is needed to ensure compliance with the water quality standards. Details on how these approaches are being implemented for point sources are described in Environmental Protection Agency (1987).

Point-source pollution is generated primarily by industries and municipalities and is generally incidental to forest and range lands. However, several kinds of operations associated with forest and range lands do generate point-source pollution. Some of these are relatively permanent and generate pollution on a year-round basis, but others are only temporary or seasonal. Common sources of potential point-source pollution on forest and range lands include: rock crushing and gravel washing; log sorting and storage; wood processing; mining; food processing; developed recreation sites; feedlots, marine vessels; remote work centers (logging and mining camps); summer homes; and organization camps. These point-sources of pollution are found, collectively, in every region, though not all are considered pollution problems in all basins. In fact, pollution from these sources is generally not significant on the national basis, but is can be significant locally if not controlled. Both technology-based and water quality-based approaches are used to control pollution from these forest-and rangelands-related point sources.

Economic Impacts of Water Quality Improvements--The water quality improvements resulting from the 1972 Clean Water Act already have been reported in Chapters 1. The quality of water in streams has been upgraded considerably since 1972. Yet the progress made to date has not been spread uniformly across the countryside. The emphasis since the 1972 legislation has been on cleaning up the major point sources of pollution. The result has been that 47 percent of the EPA grant dollars have been spent on 11 percent of the grants allocated to only 1 percent of the treatment plants nationwide, table 3.3 (Smit and Chapin, 1983).

Table 3.3--Relationships among the distributions of community size, number of grants and value of grants for wastewater treatment plant construction, 1972 to 1982.

Community size -number of people-	Number of places	Number of grants	Value of Grants
	percent	percent	percent
Less than 5,000	79	55	12
5,000 to 25,000	16	23	21
5,000 to 100,000	4	11	20
Greater than 100,000	1	11	47

Source: Smit and Chapin (1983)

Plants less than 1.05 mgd in capacity account for 79 percent of treatment plants nationwide, but they account for a total of only 8 percent of nationwide treatment capacity. In contrast, plants greater than 50 mgd capacity are only 0.6 percent of plants, but account for 39 percent of treatment capacity. So in funding construction of large plants first, the major point-source problems were addressed first.

There currently exists a substantial backlog of wastewater treatment projects in small communities. The scheduled reduction in the construction grants program funded by the Environmental Protection Agency means that financial grants to small communities will drop. The former construction grants program provided for the federal government to pay 75 percent of the cost of treatment plant construction. The new program will provide a federal grant of only 55 percent and make the communities eligible for low interest loans. For example, if the community finances its 45 percent of the cost through a loan from the Farmers Home Administration at 5 percent interest for 40 years, the loan payments should result in user charges equivalent to the charges needed to retire bonds sold at market rates to fund the 25-percent community share under the former program (Smit and Chapin 1983). As an additional incentive to small town, treatment standards for small communities were reduced by the Municipal Wastewater Treatment Grant Amendments of 1981 to allow less-expensive treatment options to be employed yet still bring the towns in compliance with the Clean Water Act. These amendments declared that treatment processes such as trickling filters and lagoons met the secondary treatment standards established for municipalities.

Feliciano (1982) summarized the economic impact of treatment plant construction grants in terms of jobs. His numbers have been modified here to convert them from a grant-dollar basis to a total-expenditure basis. Each $1 billion in expenditures for wastewater treatment plant construction provides 10,195 person-years of work for the building trades, 14,660 person-years of work for industry (manufacturing, transportation and related services and mining), and 1,840 person-years of work for engineers--a total of 26,835 person-years of work. The adjustments made by the Municipal Wastewater Treatment Grant Amendments of 1981 reduce the capital-intensity of treatment plants for small towns, so the jobs impacts of the future construction program combining grants and loans may be somewhat less. Nevertheless, the economic impact is still expected to be substantial. Further, because small towns are more uniformly distributed across the nation, the economic impact of the future program should be spread more broadly across the land. Smaller firms will have more opportunities to participate in the construction program.

<u>Nonpoint Sources</u>--As in the case of point-source pollution, nonpoint-source pollution has two abatement approaches: regulatory and non-regulatory. Regulatory controls tend to apply where cause-and-effect relationships can be most easily established, although many exceptions exist. Examples include controls on runoff from mining, construction, and silvicultural activities in States where these are significant industries. Other nonpoint categories such as agricultural runoff are more likely to be subject to non-regulatory--that is, voluntary--controls, with incentives and technical support provided by a variety of State and Federal agencies. Nonpoint pollution controls are often applied on a case-by-case basis, and are administered at the local or State level.

<u>Nonpoint-Source Pollution from Forests and Rangelands</u>--The Association of State and Interstate Water Pollution Control Administrators (1986) is the most complete recent survey on the extent of the nonpoint-source pollution situation in the United States. The Association reported on nonpoint-source programs at the Federal, State, and local levels as of 1984. They found 354 programs at the State and local level and 32 programs in 17 Federal agencies that manage nonpoint-source-related activities and affect water quality.

The most frequently listed Federal programs were those of the Soil Conservation Service, the Forest Service, the Office of Surface Mining, the Bureau of Land Management, and the U.S. Army Corps of Engineers. State programs ranged from dredge-and-fill permitting and fish and wildlife management to pesticide applicator licensing and coastal zone/floodplain management. Local programs listed most frequently included those of soil and water conservation districts and planning/zoning commissions and those having to do with permitting of well construction and septic systems and erosion/sediment control.

States reported that 69 percent of State- and locally-initiated nonpoint-source programs include some form of regulatory authority. Grants, loans, tax abatement, and other incentives are included in 14 percent of the State and local programs, with most of these programs directed towards agricultural activities. The States concluded that effective nonpoint-source programs

require close cooperation among State, Federal, and local governments, along with private interests and the public at large.

The Current Status of State Water Quality Laws Affecting Forestry Operations

Most modern efforts to maintain or improve water quality in the individual states have stemmed from the Clean Water Act. The amendments stressed strong state action to control water pollution, with federal oversight. Although many states had enacted water quality legislation of some type prior to 1972, only a few of the laws specifically addressed silvicultural pollution of water--and then primarily stream blockage with logging debris. Two sections of the Clean Water Act have direct implications for forestry operations.

Section 404 requires that a permit be obtained for the discharge of dredge and fill material into navigable waters and adjacent wetlands. Under this authority, the Corps of Engineers may require permits when drainage projects are conducted for certain silvicultural operations in wetlands--such as clearcutting and site preparation, and road and skid trail construction. Additional discussion about the 404 Program is found in the wetlands sections of this chapter and Chapter 7.

Section 208 mandates that individual states develop and implement areawide nonpoint-source pollution management plans, subject to approval of EPA. Silvicultural activities are designated as one type of nonpoint-source pollution that must be addressed in the plans. Thus most state efforts with respect to water quality in recent years have been in conjunction with Section 208. However, despite the state activity that has resulted from Section 208, many believe that nonpoint-source pollution was still an impediment in achieving national water quality goals. This led to a major revision of the law in the form of the 1987 Water Quality Act. A principal component of the new law--Section 319--contains specific language intended to improve control of nonpoint-source pollution.

Section 319 requires each state to prepare, by August 1988, detailed water quality management plans that identify bodies of water not in compliance with water quality standards because of nonpoint-source pollution. The plans are also required to identify categories and individual nonpoint sources that violate water quality, and to describe proposed control mechanisms. Each state must then devise either regulatory or voluntary programs to control nonpoint-source pollution--including that emanating from forestry activities. In implementing their nonpoint control mechanisms--whether voluntary or mandatory--the states may base compliance on either the use of BMPs or on state water quality standards.

BMPs are the optional methods, measures, or practices for preventing or reducing water pollution, including--but not limited to--structural controls, operating and maintenance procedures, and scheduling and distribution of activities. Water quality standards, on the other hand, are specific water quality criteria, both narrative and numeric, for the designated water bodies of a state.

Existing state water quality and related legislation has been examined for this report, including how such laws interact with forestry activities and how the individual states are currently addressing silvicultural-related nonpoint water pollution. Tables C-1 through C-4 in Appendix C present the statutory details for each state, together with a brief discussion of the implications of current legislation for silvicultural operations. The following paragraphs broadly summarize the findings.

Each of the 50 states has in force a general water quality law. Some are more specific than others, but all are broad in scope. Each of these statutes authorizes the administering agency to control water pollution by promulgating standards and regulations. Some of the laws also prescribe a discharge permit system--usually optional with the administering agency. Only a few of these general laws specifically address forestry operations, and only a few distinguish between point and nonpoint sources of water pollution. Virtually all of them, however, are broad enough in language to encompass by implication nonpoint-source pollution--including that emanating from forestry activities--even when the statutory language fails to mention the terms "forestry or silvicultural" and "nonpoint."

The South--Most of the general water quality laws in the South were passed in the 1960s and 1970s. In 11 of the 14 southern states, neither the general statute nor the regulations promulgated under it address forestry activities. Two states--Tennessee (by statute) and Louisiana (by regulation)--specifically exempt silvicultural operations from the Act's provisions. West Virginia includes forestry under its Act's umbrella except where site-specific silvicultural BMPs are utilized. All of the southern states except Texas use a voluntary forestry BMP program to control forestry-related nonpoint-source pollution. Texas has no program whatsoever and has taken the position that there are no such problems in the state. Some of the southern states have also passed special water-related laws, such as stream obstruction, wetland protection, and scenic rivers legislation, that impact to some degree on forestry operations in special situations.

The North--Each of the northern states has a general water quality law, most of which were enacted prior to 1960--the Wisconsin law was enacted in 1913. Thus this type of statute has generally been in force longer in the North than in other parts of the country where the majority of such laws are much newer. Some of the northern statutes (or the regulations issued under them) specifically address forestry operations, as do statutes in the West. But other northern states, primarily in the Midwest, have statutes that omit specific references to forestry. These states parallel the case in the southern states. Even those that do not, however, are broadly enough written to apply by implication to silvicultural nonpoint sources. Forestry nonpoint-source water pollution in the North is subject to a wide range of control mechanisms ranging from formal regulation in Massachusetts under that state's Forest Practice Act to no program whatsoever in Delaware and Rhode Island. Maine, New York, Vermont and New Hampshire utilize a quasi-regulatory approach with a tie-in to the general water quality law. Maryland, Connecticut, New Jersey, and Pennsylvania approach the situation by means of a voluntary BMP program. In certain cases (very-large operations) forestry harvesting activities in Pennsylvania are subject to state regulation under the general

water quality law. Most northern states have also passed a variety of special wetland and shoreline protection laws that contain restrictions on forestry practices in special situations, as well as water-related laws that impact certain forestry operations, such as stream obstruction and scenic rivers statutes.

The West--All but three of the general water quality laws in the West were passed in the 1960s and 1970s. The Oregon and Utah statutes were enacted in the 1950s and Idaho's in 1947. Eight of the 17 laws either specifically address forestry nonpoint pollution control in the basic legislation or do so by regulation or administrative procedure. In California, Idaho, Oregon, Nevada, New Mexico, and Washington forestry water quality problems are controlled through the state forest practice acts and the mandatory BMPs promulgated under those laws. In Montana, forestry operations must adhere to BMPs developed by the Department of Public Lands. In Alaska, the BMPs written under the authority of the state forest practice act are voluntary -- thus if they are not utilized, or are used and fail to prevent violations set forth under the general water quality act, the regulatory provisions of the latter can be invoked. In Utah, forestry nonpoint pollution is addressed through state certification of local BMPs as directed by regulations issued under the general water quality statute. Arizona, Hawaii, Colorado, Kansas, Nebraska, North and South Dakota,and Wyoming have no forestry nonpoint programs in place. A number of the western states have also enacted special water protection statutes--such as stream obstruction, scenic river, and wetland protection laws--that place limitations on forestry operations in special situations.

Summary--A review of the state water quality legislation that affects forestry practices in the East indicates that most of the laws have not been very restrictive to date--with the exception of several northern states--but that the opposite situation exists in much of the West. In many situations in the East, however, the statutes in place do have the potential to be more stringently invoked with respect to silvicultural operations. In addition, new state legislation is being considered in a number of eastern states to replace inconsistent, and often conflicting local land use ordinances--many of which address water resource protection. These laws could also result in more pervasive and strict control of silvicultural activities. Passage of the 1987 Water Quality Law, with its strong emphasis on state action, indicates that nonpoint-source water pollution prevention will continue to be both a national and a state priority. New state laws will certainly be passed, and old ones amended, that will address in more absolute terms nonpoint-source pollution from silvicultural activities.

Water Quality Improvements Since Last Assessment

Major advances have been made in improving instream water quality since 1972. Comparison of State reports in the appendix to Environmental Protection Agency (1987) with previous inventory reports demonstrates where and how much water quality has improved. Case studies in the 1987 report show even more impressive results obtained in specific areas.

The Clean Water Act set goals and the Nation mobilized to attain them. The 1986 National Water Quality Inventory concludes that industries mobilized to

clean up point sources faster than municipalities. In the decade following passage, biochemical oxygen demand loads from municipal plants decreased 46 percent and industrial loads at least 71 percent (Association of State and Interstate Water Pollution Control Administrators 1984). The costs of municipal wastewater treatment today are double what was being spent in 1972 (in constant dollar terms), and industrial costs are 50 percent higher. These expenditure patterns portray the additional emphasis water pollution received following passage of the Clean Water Act.

As point sources of pollution have been cleaned up, the effects of nonpoint sources have become more apparent. If anything, their effect was underestimated when the original legislation was passed in 1972. Widespread increases in chloride (highway salting), nitrate (fertilizers), and sulfate (coal combustion products) concentrations are thought to be linked to nonpoint-source pollution (Foxworthy and Moody 1986). Sediment from soil erosion is also a major nonpoint-source pollution problem, emanating mostly from agricultural areas. Water quality programs that formerly emphasized control of point-source pollution are now shifting to programs emphasizing the control of nonpoint sources of pollution, the protection of ground-water quality, and the cleanup of toxic-waste disposal sites. This shift in emphasis is projected to continue into the next century because these problems are more difficult to address.

Summary

Background water quality levels for undisturbed forests and rangelands portray the long-run water quality goals that land managers seek to perpetuate. Before the mid-1960s, offstream uses downstream from forests and rangelands resulted in significant declines in water quality. Dilution of wastes with instream flows was a commonly accepted policy (Wollman and Bonem 1971). The Clean Water Act changed that policy and set goals to returning water to fishable and swimmable levels and of eliminating discharges causing pollution. The nation embarked on what has become a very successful effort to clean up discharges; efforts over the past 15 years have largely met the established goals. The cost of the cleanup has been considerable--$300 billion for pollution abatement between 1972 and 1984; $172 billion for capital equipment alone[8]. But the benefits appear worth it.

It is unlikely that the Nation will embark on a program of similar magnitude in the near future. Any additional cleanup would require larger investments to obtain much smaller increments of improved water quality; successive increments of pollution become more and more costly to remove. Consequently, one cannot take improvements made in water quality since 1972 and project that additional improvements in water quality will continue at that rate into the future.

The quality of water supplies available nationwide after 2000 will be somewhat better than current quality, but a major improvement nationwide is not anticipated. The opportunity for the most significant improvements in quality will come from reductions in nonpoint-source pollution. The prevalence of municipalities and industries causing with locally significant water quality problems will diminish as smaller point-source discharges are cleaned up.

The quality of water emanating from forested and rangeland watersheds is projected to be higher than quality measured downstream. Maintaining water quality levels that will not foreclose water use options of downstream users while engaging in land resource management activities will represent the key challenge to forest and range managers in the 21st century.

Wetlands Supply Trends[9]

The use of wetlands--the marshes, tundras, swamps, bogs, bottomlands and tundra that comprise about 5 percent of the contiguous United States and about 60 percent of Alaska--is a source of controversy. Some want to convert these areas to other uses while others want them left in their natural state. Some wetlands provide natural ecological services, such as floodwater storage, erosion and sedimentation control, nutrient removal to improve water quality and support food chains, and habitat for wildlife and fish. Consequently, wetlands offer varied recreational, educational, and vocational opportunities.

Wetlands are usually characterized by emergent plants growing on soils that are periodically or normally saturated with water.[10] Wetlands occur along gradually sloping areas between uplands and deep-water environments, such as rivers, or form in basins that are isolated from larger water bodies. Of the 90 million acres of vegetated wetlands in the contiguous U.S., 95 percent are located in inland, freshwater areas. The remainder are coastal, saltwater environments. In addition, it has been estimated that nearly 60 percent of the State of Alaska--over 200 million acres--is covered by wetlands.[11]

Wetlands Conversion Rates and Responsible Activities

Within the past 200 years, 30 to 50 percent of the wetlands in the contiguous U.S. have been converted to other uses, such as agriculture, mining, forestry, oil and gas extraction, and urbanization. According to the most recent federal survey, 11 million acres of wetlands in the lower 48 states were converted (the net change) to other uses between the mid-1950s and the mid-1970s. This amount was equivalent to a net loss each year of 550,000 acres, or about 0.5 percent of remaining wetlands annually. Eighty percent of the actual losses were due to draining and clearing wetlands for agriculture. Although some losses were due to natural means, such as erosion, sedimentation, or subsidence, at least 95 percent of actual wetlands losses over the period between 1960 and 1985 were due to human activities of some kind.

The current annual rate of wetlands loss is about 300,000 acres annually. The decline from the 550,000-acre rate of the 1950s to 1970s is due primarily to declining rates of agricultural drainage, and secondarily to government programs that regulate wetlands use. The U.S. Army Corps of Engineers' program under Section 404 of the Clean Water Act regulates many of the activities that involve disposal of dredge or fill material. Prior to this legislation, much of this material was deposited in wetlands filling them in. While <u>coastal</u> wetlands are protected reasonably well by a combination of federal and state regulatory programs, <u>inland</u> wetlands, which comprise 95 percent of the Nation's wetlands, are poorly protected.

Wetland conversion rates and activities vary significantly throughout the country. For example, conversions in the Lower Mississippi water resource region occurred at rates three times the national average from the mid-1950s to mid-1970s. In contrast, conversion rates along the Atlantic coast (excluding Florida) were only 30 percent of the national average. Overall, wetland conversions occurred in coastal areas at rates that were 25 percent less than inland conversion rates during the two-decade period.

Ninety-seven percent of actual wetlands losses occurred in inland freshwater areas from the mid-1950s to mid-1970s. Agricultural conversions involving drainage, clearing, land leveling, groundwater pumping and surface water diversions were responsible for 80 percent of the conversions. Of the remainder, 8 percent resulted from construction of large impoundments and reservoirs, 6 percent from urbanization, and 6 percent from other causes, such as mining, forestry, and road construction. Fifty-three percent of the inland wetlands conversions occurred in forested areas, mainly bottomlands.

Of the actual losses to coastal wetlands, 56 percent resulted from dredging marinas, canals, port developments, and to a lesser extent, from erosion. Twenty-two percent of the losses resulted from urbanization. Fourteen percent were due to disposal of dredge spoil or beach creation. The balance of the losses were due to the natural or human-induced transition from saltwater to freshwater wetlands (6 percent) and agriculture (2 percent).

Projected Future Losses

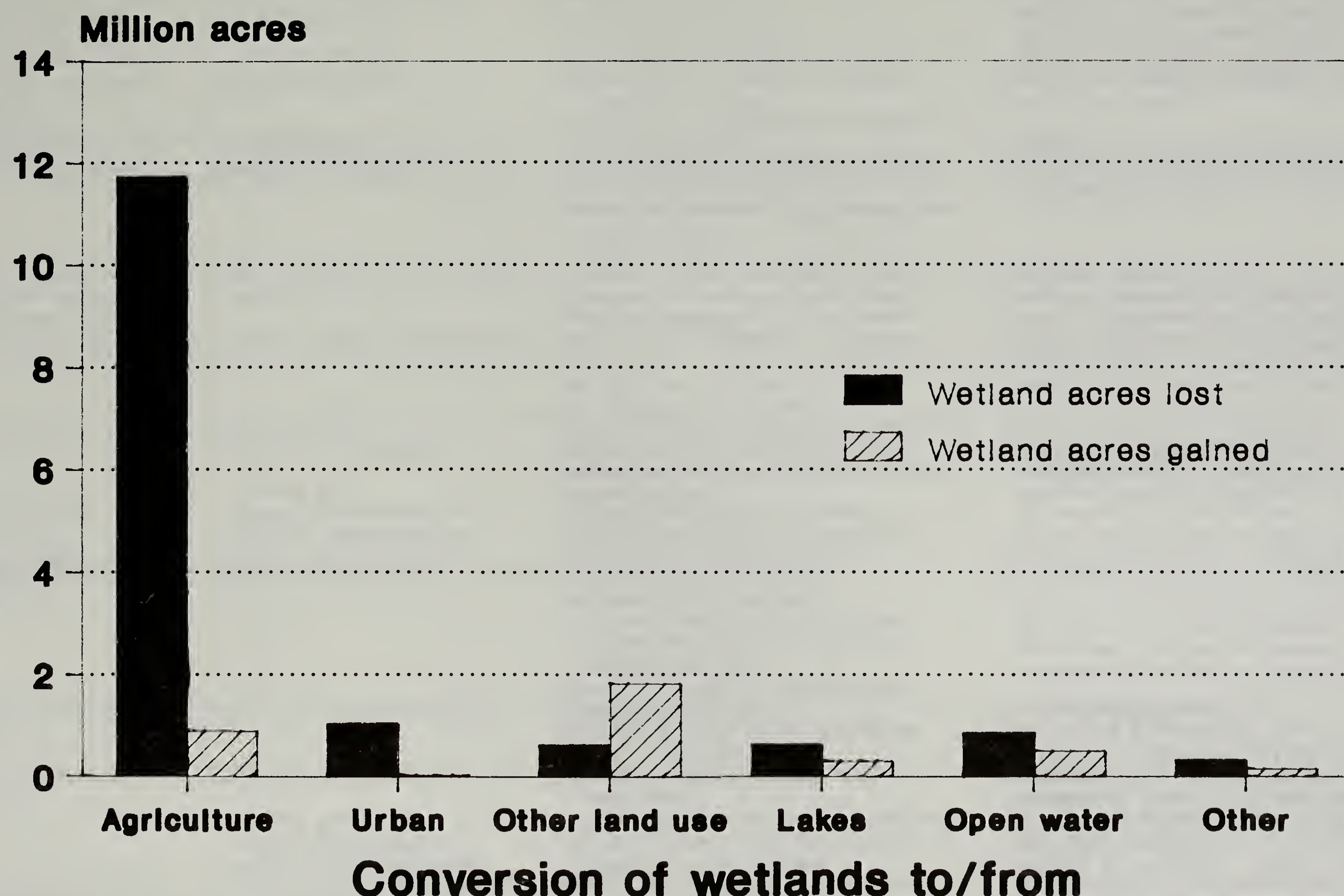
Agriculture is the leading cause of wetlands losses, figure 3.1 and table 3.4. If agriculture losses are ignored, the losses from all the other land uses balance the gains in wetlands from all land uses. Consequently, the future of wetlands is inextricably linked to projected future changes in agriculture.

The RCA Appraisal (Department of Agriculture 1987) concluded that remaining wetlands need protection. Nearly half of the remaining nonfederal wetlands and almost all the palustrine wetlands in the United States are potentially subject to conversion for agriculture. The 1982 Natural Resource Inventory reported the acreage of wet soils and wetlands that have "potential for conversion", where that means that similar lands have already been converted in prior years. About 5.2 million acres of wetlands have high or medium potential for conversion. The wetlands most likely to be drained and converted to agriculture fall into two general categories:

— small wetland areas, either natural or made by humans, that interfere with a farmer's agricultural operations

— relatively large areas presently in mature hardwood stands where the value of the timber helps offset the costs of clearing the land, where land drainage and shaping costs are relatively low, where outlets for drainage water are readily available, and where continued profitable ownership of the land requires the development of an annual income from the land. Although some wetlands have been converted directly to agricultural uses, about half were originally forested and may have entered agriculture use after being cut over for timber.

Figure 3.1--Trends in the conversion of freshwater and saltwater wetlands, mid-1950s to mid-1970s



Source: Fish and Wildlife Service (1982)

Table 3.4--Agricultural conversions of wetlands from the mid-1950s to mid-1970s

How accomplished	Important regions/ wetlands types	Reasons	Trend
Major drainage, flooding	Prairie potholes of Minnesota, North Dakota, South Dakota/ shallow, moderately deep marshes and seasonally flooded flats	Opportunity to gain additional cropland Elimination of nuisance by avoiding potholes within cropland. Change in farming from diversified crops and livestock to row crops and small grain Increase in tractor horsepower Increases avoidance costs Increase in center-pivot irrigation Climatic variations Absence of financial incentives to maintain wetlands Drainage opportunities from channel projects and rural roads ditches Tax benefits for drainage	Of original, 25 to 30 percent of acres remain; greatest percentage and acreage drained in Minnesota. However, this is extremely variable within region, varying by 12 to 95 percent. Continuing conversion. Annual drainage rates estimates range from 0.1 to 5.0 percent. Almost half remaining wetlands are under protective programs; of these, 90 percent are permanent forms
Major drainage, flooding, excavation, land-leveling	Nebraska Rainwater Basin/ shallow, moderately deep marshes and seasonally flooded flats	Intensify or expand cropland Drainage opportunities through rural road upgrading and improvement Drought incidence Possible Federal or State cost-sharing assistance for reuse systems or leveling associated with irrigation Tax benefits for drainage Available farm equipment	Continuing conversion. Remaining are 15- to 25- percent original acres and 10- to 15- percent original basins. Protection programs conver 50 to 85 percent of remaining acreage. Nearly 90 percent of these are in permanent forms
Ground water pumping, associated land-leveling and filling	Nebraska Sandhills/wet meadows	Conversion of rangeland to cropland Long-term reduction in ground water levels and seasonal ground water variations due to expanding center-pivot irrigation Increase efficiency of center pivot Expand hay production into wetter areas	Accelerating conversion rate in last 10 years. Remaining are 85 to 95 percent of original acres and more than 95 percent of original basins
Ground water pumping, surface water diversions	Nebraska-Central Platte Valley/ wet meadows	Indirect impact of regional irrigation development Conversion of rangelands to cropland	Of original wet meadows, 30 to 45 percent remaining
	California-Klamath Basin/ emergent marshes	Conversion of rangeland to cropland	Of original acreage, 40 percent remaining. Continuing conversions on private and managed wetlands. Approximately 50 percent of remaining wetland and lake areas in national wildlife refuges and State wildlife management areas

Table 3.4--Agricultural conversions of wetlands from the mid-1950s to mid-1970s (continued)

How accomplished	Important regions/ wetlands types	Reasons	Trend
Normal farming: land-leveling of flood-irrigated areas, shift in crops, shift in planting and harvest schedules	California-Central Valley/ emergent marshes	Less water available Increased pumping costs Clean farming practices Pesticide/herbicide use Flood control Irrigation technology	More than 90 percent converted from 1850 to 1978. Continuing conversions of ricelands to less water-intensive crops. Degradation of habitat on secondary wetland areas. Of remaining acreage, 20 percent in public ownership
Drainage, land-leveling	California-Central Valley/ emergent marshes	Less water available Higher taxes on nonagricultural lands Increased pumping costs Degradation of habitat on secondary wetland areas	See above description of overall trends of Central Valley. Conversion of private wetlands to agriculture. Reduction of flooded public acreage
Clearing vegetation	Lower Mississippi River Valley/ bottom land hardwoods	Soybeans demand Relative price of timber Drought incidence Flood-control projects	Significant conversion prior to 1937. Forty-four-percent reduction, 1937-1977. Forest remaining 0 to more than 60 percent (1979). Rate of clearing peaked 1967 (except Louisana). Clearing rates related forest left. Continuing conversion
Clearing vegetation drainage	North and South Carolina/ bottom land hardwoods	Relative price of timber Improved drainage equipment Refined use of lime, fertilizer, pesticides Improve seed stocks Agribusiness investment	Increase from 1930's to 1950's from reforestation of abandoned farms. Increasing rate of conversion 1950s to 1970s
Clearing vegetation, drainage	North Carolina/pocosins	Improved drainage equipment	By 1979, 33 percent totally developed. Of remaining areas, 65 percent owned by agricultural and forest products industries. Five percent protected from drainage through public ownership or lease
Clearing vegetation, drainage	South Carolina/carolina bays	Large-scale agriculture Forestry	Ninety-five percent altered
Clearing vegetation, drainage	South Florida/cypress	Agricultural and urban uses	Conversions occurred from 1900 to 1973, including 25 percent of cypress domes and stands and 12 percent of scrub cypress. Continuing conversions
Lack of drainage, ditch maintenance	New England/wooded wetlands	Agricultural abandonment	Wetlands recreated

Table 3.4--Agricultural conversions of wetlands from the mid-1950s to mid-1970s

How accomplished	Important regions/ wetlands types	Reasons	Trend
Mowing, seeding, fertilizing, grazing	South Florida/wet prairies, sawgrass	Expanded agriculture Transform areas to dry land to prepare for urban development (and avoid regulations associated with fill in wetalands)	Conversion of 45 to 52 percent of wetlands from 1900 to 1973. Continuing conversions

SOURCE: U.S. Congress (1984)

Nearly half the 5.2 million acres with high or medium conversion potential are in the South. Another 30 percent are in the North.

The Food Security Act of 1985 (Public Law 99-447) contains a "swampbuster" provision that makes farmers ineligible for certain USDA programs if they convert wetlands. The Act provides for restrictions or prohibitions on federal commodity payments and loans to farmers who produce crops on newly converted wetlands. The Fish and Wildlife Service and Soil Conservation Service have cooperated to define the types of vegetation and types of soils characterizing wetlands eligible for protection under this program. There are 17 million acres of wetlands having some potential for crop production. Heimlich (1988) concluded that the swampbuster provision will likely retard conversion on only about one-third of these acres--the 5.2 million acres with medium to high crop production potential. Nearly half of the 5.2 million acres are in the South. Another 30 percent are in the North. Wetlands conversion in much of the South Atlantic-Gulf region will likely **not** be affected by withholding of farm program benefits, according to Heimlich's analysis. Additional information on the swampbusyter provision is found in Heimlich and Langner (1986).

While the Corps' Section 404 program and the swampbuster provision of the Food Security Act discourage conversion of wetlands, other laws and regulations exist that subsidize wetlands conversions. For example, the federal income tax law (and many states' income tax laws) authorize tax credits for investments, deductions for expenses of operations, and special provisions for resource depletions. Conversion of wetlands has historically been judged an investment whose costs are eligible for special treatment when income taxes are computed.

Local property taxation administration also favors conversion in some areas. For example, U.S. Congress (1984) cited the case of a hunting club in California that owned a large parcel of wetlands. When the recorded land use was changed to recreational land from wetlands, the increased tax burden made it difficult to maintain the club. Financial problems brought on by increased assessed values can lead to sales to developers, making conversion more imminent. Many local governments provide property tax breaks where the assessed value is dependent upon the land use to encourage landowners to keep land in forest cover. Similar local property tax relief would be useful to help preserve wetlands.

Other Uses of Wetlands Affected by Conversions

Wetlands provide food and habitat for many game and non-game animals. For some species, wetlands are essential for survival. For example, waterfowl require wetlands for breeding and nesting. These birds nest primarily in northern freshwater wetlands in the U.S. and Canada in the spring and summer, but use wetlands for feeding and cover in all parts of the country during migration and overwintering. The survival, return, and successful breeding of many species, therefore, depend upon a wide variety of wetland types throughout North America. It is no coincidence that the major migratory routes, breeding and nesting areas, and overwintering areas correspond with regions of greatest wetland concentrations, and that waterfowl populations have declined along with the decline in wetlands acreage.

For other species, wetlands serve more general needs. Coastal marshes and certain types of inland, freshwater wetlands achieve some of the highest rates of plant productivity of any natural ecosystem. This high productivity often supports varied and abundant animal populations within a complex food chain. During the growing season, less than 15 percent of the plant biomass in saltwater marshes is consumed directly by foraging animals. After the plants die, up to 70 percent of the plant material is broken down into small particles and flushed into adjacent water where it becomes a potent food source for estuarine-dependent fish and shellfish.

Several fish species are also dependent upon wetlands, preferring to spawn in shallow, vegetated water. Wetlands afford abundant food for fingerlings and their vegetation offers protection from currents, sunlight, and predators.

Wetlands are home to wildlife of economic importance, including minks, muskrats, and nutria (furbearers); alligators (hides and meat); and crayfish and assorted fish and shellfish (meat). Other plants and animals could become equally important if proven to be sources of food, chemicals, or extracts.

Other important functions of wetlands include shoreline stabilization, groundwater recharge, and recreation. Vegetated freshwater wetlands significantly reduce shoreline erosion caused by large waves and major coastal riverine flooding. Some wetlands that are hydrologically connected to the groundwater system provide aquifer recharge through infiltration and percolation of surface water. In general though, recharge rates in uplands areas are typically higher than for wetlands. Finally, because of the habitat wetlands provide for fish and wildlife, they are prime recreation areas for wildlife observation and nature photography, in addition to hunting and fishing.

In the wildlife and fish assessment that is a companion to this report, Flather (1988) provides additional information on wetlands and their importance.

Summary

The historic rate of wetlands conversion of the mid-1950s to mid-1970s has dropped from 550,000 acres annually to 300,000 acres in the mid-1980s. The Nearly half the land converted during this period has been forested palustrine wetlands. The predominant cause for converting wetlands has been to provide additional agricultural production.

About 5.2 million acres of wetlands are potentially suitable for conversion to agriculture. Recent changes in agricultural policy will preclude significant additional conversions of these wetlands, particularly forested ones, to agricultural use. The rate of wetlands conversion to agriculture is expected to dip significantly as the swampbuster provisions take effect. By the year 2000, conversions are projected to be around 100,000 acres annually. Whether there is any further dip in the conversion rate will depend on whether or not additional disincentives can be created for conversion to non-agricultural land uses. There remain 11.8 million acres of wetlands only marginally suitable for agriculture that may still move easily into non-agricultural land uses, unaffected by the swampbuster provision.

Wetlands support a rich and diversified population of plants and animals--many of economic importance. Further, wetlands provide considerable recreation opportunity and other social benefits, such as erosion control. The continuing conversion process chips away at the benefits wetlands provide, resulting in losses to society for which adequate compensation cannot be provided.

Summary

This Assessment projects that water supply quality to 2040 will fall somewhere below the baseline levels for forest and rangelands (because some sites will undergo short-term disturbances) and somewhere above current distribution of quality levels based upon designated uses (because efforts to control nonpoint-source pollution are just beginning to bear fruit). The ability to use most waters for fishing and swimming captures the essence of current instream water quality. The emphasis then for forest and rangelands managers is to preserve **the volume** and **quality** of water for instream flows that promote fish and wildlife habitat and recreation.

The acreage of wetlands on federal lands will remain at current levels throughout the planning period due to increased sensitivity to the ecological, economic, and social value of wetlands. On private lands, acreage will continue to decrease, but at a slower pace through 2020. The net result by 2020 will be about 94 million acres, an area that stays constant to 2040.

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Notes

1. A "stock" resource is one whose supply is fixed or set at the beginning of the planning period. The quantity available cannot be increased, but use can decrease the amount.

2. Managers have no method capable of making significant regional or national increases in water supplies. Cloud seeding, where it has been successful, has only affected specific localities at intermittent intervals.

3. This section is taken largely from Tennant (1975) and first appeared in the 1979 RPA Water Assessment.

4. U.S. Department of Agriculture (1987) concluded that the trend in damages is increasing at an annual rate of $30.0 million (1984 dollars).

5. This section is drawn largely from U.S. Forest Service (1981) and the U.S. Environmental Protection Agency's (1987), National Water Quality Inventory: 1986 Report to Congress.

6. STORET is an acronym for the U.S. Environmental Protection Agency's water quality data storage and retrieval program.

7. The numbers in table 3.2 do not necessarily represent an "average" water quality. The levels of these constituents are a function of the time of day as well as flow characteristics. The quality samples are usually collected during day time and during non-storm periods, so diurnal variation and water quality effects of storm flows are not well represented in this data.

8. U.S. Environmental Protection Agency (1987, table 5.4). The totals are in 1982 constant dollars.

9. This section is drawn largely from U.S. Congress (1984).

10. This Assessment adopts a wetlands definition following the one employed by the Fish and Wildlife Service of the U.S. Department of the Interior for the purpose of mapping and land classification. There is a second, and more restrictive, definition of wetlands employed by federal agencies--principally the U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency--for the purpose of regulation. Under the former definition, there were 99 million acres of wetlands in the contiguous U.S. in the mid-1970s. Using the latter definition, there were only 64 million acres of wetlands. For example, under the definition used here, the drier sections of bottomland hardwood sites are included as wetland but the Corps of Engineers does not exercise regulatory control over these areas. The differences in definition have led to considerable confusion, because the public often views the federal government as monolithic and does not differentiate between the different purposes behind the two definitions.

11. The frozen tundra is another example of a site that meets the Fish and Wildlife Service's definition of wetland--soils that are periodically or normally saturated with water--albeit frozen water. The Corps of Engineers and Environmental Protection agency ignore such sites for purposes of regulating wetlands use.

Chapter 4

COMPARISON OF PROJECTED DEMAND AND SUPPLY SITUATIONS

Plentiful Supplies and Shortages

The generalized water balance by water resource region was introduced in table 1.2 to illustrate the current water use situation. The surplus/deficit column indicated how much water is available in the year of mean precipitation for offstream water uses. The water balance was extended in table 3.2 to account for variations in precipitation between the mean and two lower levels of precipitation--the 80-percent level, expected to be exceeded 4 years in 5; and the 95-percent level, expected to be exceeded 19 years in 20.

The comparison of projected supplies and demands is presented in this chapter through use of the most complete form of the generalized water balance approach, table 4.1. Offstream consumptive uses from 1985 to 2040--the demand projections--are incorporated in this table. The surplus/deficit column now shows where supplies are expected to be plentiful throughout the next 5 decades and where shortages are expected. It is important to note that table 4.1 presents a comparison where two variables play key roles because they are linked and each is only allowed to be in one of two states. The two variables are rainfall condition and instream flow requirements. Rainfall condition is either "average" (the mean expectation) or "dry" (the 80-percent level). Instream flow conditions are linked to the rainfall situation. The instream flow providing optimal fish and wildlife habitat is paired with the average rainfall expectation. The instream flow providing good survival habitat is paired with the dry rainfall condition (80-percent expectation). In essence, this pairing produces surpluses/deficits that bracket a continuum where flows are likely to occur. Thus, it is possible that the surplus in an average rainfall year is less than the surplus in a dry year because of the accompanying shift in instream flow assumptions from optimal to good survival habitat. Moreover, where deficits occur, the implication is that one or more of the assumptions inherent in the water balance are being violated. The most obvious one is the instream flow requirement. Deficits typically imply that less than the assumed habitat is being provided--for the dry condition, deficits infer that poor survival habitat is provided. The assumption second most likely to be violated is the groundwater overdraft situation. Deficits imply that the overdraft is higher (worse) than estimated.

Table 4.1--Generalized water budget for average and dry years, 1985 to 2040, by water resources region

Water resource region	Rainfall Condition[1]	Renewable water supply[2]	Ground-water overdraft[3]	Imports or exports[4]	Reservoir net evaporation[5]	Offstream consumptive use[6] Agriculture	Offstream consumptive use[6] Non-agriculture	Average stream outflow[7]	Instream flow requirement[8]	Surplus or deficit[9]
		billion gallons per day								
New England	1985 avg.	77.30	0.00	0.00	0.20	0.06	0.28	76.77	69.00	7.77
	2000 avg.	77.30	0.00	0.00	0.20	0.07	0.40	76.63	69.00	7.63
	2000 dry	62.15	0.00	0.00	0.20	0.07	0.40	61.48	46.40	15.08
	2010 avg.	77.30	0.00	0.00	0.20	0.07	0.45	76.58	69.00	7.58
	2010 dry	62.15	0.00	0.00	0.20	0.07	0.45	61.43	46.40	15.03
	2020 avg.	77.30	0.00	0.00	0.20	0.07	0.49	76.54	69.00	7.54
	2020 dry	62.15	0.00	0.00	0.20	0.07	0.49	61.39	46.40	14.99
	2030 avg.	77.30	0.00	0.00	0.20	0.07	0.52	76.50	69.00	7.50
	2030 dry	62.15	0.00	0.00	0.20	0.07	0.52	61.95	46.40	15.55
	2040 avg.	77.30	0.00	0.00	0.20	0.08	0.56	76.47	69.00	7.47
	2040 dry	62.15	0.00	0.00	0.20	0.08	0.56	61.32	46.40	14.92
Mid-Atlantic	1985 avg.	96.50	0.00	-0.70	0.20	0.31	1.42	93.87	68.84	25.03
	2000 avg.	96.50	0.00	-0.70	0.20	0.36	2.14	93.11	68.84	24.27
	2000 dry	75.03	0.00	-0.70	0.20	0.36	2.14	71.64	57.90	13.74
	2010 avg.	96.50	0.00	-0.70	0.20	0.37	2.42	92.81	68.84	23.97
	2010 dry	75.03	0.00	-0.70	0.20	0.37	2.42	71.34	57.90	13.44
	2020 avg.	96.50	0.00	-0.70	0.20	0.39	2.66	92.55	68.84	23.71
	2020 dry	75.03	0.00	-0.70	0.20	0.39	2.66	71.08	57.90	13.18
	2030 avg.	96.50	0.00	-0.70	0.20	0.40	2.90	92.30	68.84	23.46
	2030 dry	75.03	0.00	-0.70	0.20	0.40	2.90	70.83	57.90	12.93
	2040 avg.	96.50	0.00	-0.70	0.20	0.41	3.14	92.05	68.84	23.21
	2040 dry	75.03	0.00	-0.70	0.20	0.41	3.14	70.58	57.90	12.68
South Atlantic-Gulf	1985 avg.	213.00	0.00	0.00	0.50	2.32	2.64	207.54	188.70	18.84
	2000 avg.	213.00	0.00	0.00	0.50	2.71	3.62	206.16	188.70	17.46
	2000 dry	154.51	0.00	0.00	0.50	2.71	3.62	147.67	127.81	19.86
	2010 avg.	213.00	0.00	0.00	0.50	2.84	4.07	205.59	188.70	16.89
	2010 dry	154.51	0.00	0.00	0.50	2.84	4.07	147.10	127.81	19.29
	2020 avg.	213.00	0.00	0.00	0.50	2.96	4.47	205.07	188.70	16.37
	2020 dry	154.51	0.00	0.00	0.50	2.96	4.47	146.58	127.81	18.77
	2030 avg.	213.00	0.00	0.00	0.50	3.05	4.87	204.57	188.70	15.87
	2030 dry	154.51	0.00	0.00	0.50	3.05	4.87	146.08	127.81	18.27
	2040 avg.	213.00	0.00	0.00	0.50	3.14	5.27	204.09	188.70	15.39
	2040 dry	154.51	0.00	0.00	0.50	3.14	5.27	145.60	127.81	17.79

Notes:

See last page of the table.

Table 4.1--Generalized water budget for average and dry years, 1985 to 2040, by water resources region (continued)

Water resource region	Rainfall Condition[1]	Renewable water supply[2]	Ground-water overdraft[3]	Imports or exports[4]	Reservoir net evaporation[5]	Offstream consumptive use[6] Agriculture	Offstream consumptive use[6] Non-agriculture	Average stream outflow[7]	Instream flow requirement[8]	Surplus or deficit[9]
		billion gallons per day								
Great Lakes	1985 avg.	76.80	0.00	-1.30	0.30	0.38	0.88	73.94	63.95	9.99
	2000 avg.	76.80	0.00	-1.30	0.30	0.44	1.24	73.52	63.95	9.57
	2000 dry	61.09	0.00	-1.30	0.30	0.44	1.24	57.82	46.08	11.74
	2010 avg.	76.80	0.00	-1.30	0.30	0.46	1.39	73.34	63.95	9.39
	2010 dry	61.09	0.00	-1.30	0.30	0.46	1.39	57.64	46.08	11.56
	2020 avg.	76.80	0.00	-1.30	0.30	0.48	1.53	73.18	63.95	9.23
	2020 dry	61.09	0.00	-1.30	0.30	0.48	1.53	57.48	46.08	11.40
	2030 avg.	76.80	0.00	-1.30	0.30	0.50	1.67	73.03	63.95	9.08
	2030 dry	61.09	0.00	-1.30	0.30	0.50	1.67	57.32	46.08	11.24
	2040 avg.	76.80	0.00	-1.30	0.30	0.51	1.81	72.88	63.95	8.93
	2040 dry	61.09	0.00	-1.30	0.30	0.51	1.81	57.17	46.08	11.09
Ohio[10]	1985 avg.	140.00	0.00	0.00	0.40	0.30	1.61	137.69	122.00	15.69
	2000 avg.	140.00	0.00	0.00	0.40	0.33	2.33	136.95	122.00	14.95
	2000 dry	107.67	0.00	0.00	0.40	0.33	2.33	104.62	84.00	20.62
	2010 avg.	140.00	0.00	0.00	0.40	0.34	2.69	136.57	122.00	14.57
	2010 dry	107.67	0.00	0.00	0.40	0.34	2.69	104.24	84.00	20.24
	2020 avg.	140.00	0.00	0.00	0.40	0.36	2.99	136.25	122.00	14.25
	2020 dry	107.67	0.00	0.00	0.40	0.36	2.99	103.93	84.00	19.93
	2030 avg.	140.00	0.00	0.00	0.40	0.37	3.34	135.89	122.00	13.89
	2030 dry	107.67	0.00	0.00	0.40	0.37	3.34	103.56	84.00	19.56
	2040 avg.	140.00	0.00	0.00	0.40	0.38	3.73	135.49	122.00	13.49
	2040 dry	107.67	0.00	0.00	0.40	0.38	3.73	103.16	84.00	19.16
Tennessee	1985 avg.	43.30	0.00	0.00	0.00	0.05	0.34	42.91	38.48	4.43
	2000 avg.	43.30	0.00	0.00	0.00	0.06	0.44	42.81	38.48	4.33
	2000 dry	38.14	0.00	0.00	0.00	0.06	0.44	38.14	25.98	12.16
	2010 avg.	43.30	0.00	0.00	0.00	0.06	0.49	42.75	38.48	4.27
	2010 dry	38.14	0.00	0.00	0.00	0.06	0.49	37.59	25.98	11.61
	2020 avg.	43.30	0.00	0.00	0.00	0.06	0.55	42.69	38.48	4.21
	2020 dry	38.14	0.00	0.00	0.00	0.06	0.55	37.54	25.98	11.56
	2030 avg.	43.30	0.00	0.00	0.00	0.06	0.60	42.64	38.48	4.16
	2030 dry	38.14	0.00	0.00	0.00	0.06	0.60	37.48	25.98	11.50
	2040 avg.	43.30	0.00	0.00	0.00	0.06	0.65	42.58	38.48	4.10
	2040 dry	38.14	0.00	0.00	0.00	0.06	0.65	37.43	25.98	11.45

Notes:

See last page of the table.

Table 4.1--Generalized water budget for average and dry years, 1985 to 2040, by water resources region (continued)

Water resource region	Rainfall Condition[1]	Renewable water supply[2]	Ground-water overdraft[3]	Imports or exports[4]	Reservoir net evaporation[5]	Offstream consumptive use[6] Agriculture	Offstream consumptive use[6] Non-agriculture	Average stream outflow[7]	Instream flow requirement[8]	Surplus or deficit[9]
		billion gallons per day								
Upper Mississippi[11]	1985 avg.	79.90	0.00	2.00	0.60	0.65	0.89	79.76	69.70	10.06
	2000 avg.	79.90	0.00	2.00	0.60	0.72	1.30	79.28	69.70	9.58
	2000 dry	64.81	0.00	2.00	0.60	0.72	1.30	64.19	47.94	16.25
	2010 avg.	79.90	0.00	2.00	0.60	0.75	1.50	79.04	69.70	9.34
	2010 dry	64.81	0.00	2.00	0.60	0.75	1.50	63.95	47.94	16.01
	2020 avg.	79.90	0.00	2.00	0.60	0.79	1.66	78.85	69.70	9.15
	2020 dry	64.81	0.00	2.00	0.60	0.79	1.66	63.76	47.94	15.82
	2030 avg.	79.90	0.00	2.00	0.60	0.81	1.85	78.64	69.70	8.94
	2030 dry	64.81	0.00	2.00	0.60	0.81	1.85	63.54	47.94	15.60
	2040 avg.	79.90	0.00	2.00	0.60	0.83	2.07	78.40	69.70	8.70
	2040 dry	64.81	0.00	2.00	0.60	0.83	2.07	63.31	47.94	15.37
Lower Mississippi[12]	1985 avg.	470.00	5.80	0.00	6.00	4.28	1.83	463.69	359.00	104.69
	2000 avg.	470.00	5.37	0.00	6.90	5.10	2.60	460.76	359.00	101.76
	2000 dry	315.90	5.37	0.00	6.90	5.10	2.60	306.66	282.00	24.66
	2010 avg.	470.00	5.08	0.00	7.50	5.34	2.99	459.26	359.00	100.26
	2010 dry	315.90	5.08	0.00	7.50	5.34	2.99	305.16	282.00	23.16
	2020 avg.	470.00	4.79	0.00	8.10	5.56	3.32	457.81	359.00	98.81
	2020 dry	315.90	4.79	0.00	8.10	5.56	3.32	303.71	282.00	21.71
	2030 avg.	470.00	4.50	0.00	8.70	5.73	3.68	456.39	359.00	97.39
	2030 dry	315.90	4.50	0.00	8.70	5.73	3.68	302.29	282.00	20.29
	2040 avg.	470.00	4.20	0.00	9.30	5.90	4.07	454.93	359.00	95.93
	2040 dry	315.90	4.20	0.00	9.30	5.90	4.07	300.83	282.00	18.83
Souris-Red-Rainey	1985 avg.	7.70	0.00	0.00	0.40	0.07	0.04	7.19	3.67	3.52
	2000 avg.	7.70	0.00	0.00	0.40	0.08	0.06	7.16	3.67	3.49
	2000 dry	4.38	0.00	0.00	0.40	0.08	0.06	3.84	2.31	1.53
	2010 avg.	7.70	0.00	0.00	0.40	0.08	0.06	7.15	3.67	3.48
	2010 dry	4.38	0.00	0.00	0.40	0.08	0.06	3.83	2.31	1.52
	2020 avg.	7.70	0.00	0.00	0.40	0.09	0.07	7.14	3.67	3.47
	2020 dry	4.38	0.00	0.00	0.40	0.09	0.07	3.82	2.31	1.51
	2030 avg.	7.70	0.00	0.00	0.40	0.09	0.07	7.14	3.67	3.47
	2030 dry	4.38	0.00	0.00	0.40	0.09	0.07	3.82	2.31	1.51
	2040 avg.	7.70	0.00	0.00	0.40	0.09	0.08	7.13	3.67	3.46
	2040 dry	4.38	0.00	0.00	0.40	0.09	0.08	3.81	2.31	1.50

Notes:

See last page of the table.

Table 4.1--Generalized water budget for average and dry years, 1985 to 2040, by water resources region (continued)

Water resource region	Rainfall Condition[1]	Renewable water supply[2]	Ground-water overdraft[3]	Imports or exports[4]	Reservoir net evaporation[5]	Offstream consumptive use[6] Agriculture	Offstream consumptive use[6] Non-agriculture	Average stream outflow[7]	Instream flow requirement[8]	Surplus or deficit[9]
		billion gallons per day								
Missouri	1985 ave.	67.30	2.20	0.20	3.30	13.68	1.04	51.68	33.96	17.72
	2000 avg.	67.30	2.20	0.17	4.07	16.25	1.59	47.76	33.96	13.80
	2000 dry	51.07	2.20	0.10	4.07	16.25	1.59	31.46	20.12	11.34
	2010 avg.	67.30	2.20	0.14	4.58	17.00	1.82	46.24	33.96	12.28
	2010 dry	51.07	2.20	0.03	4.58	17.00	1.82	29.90	20.12	9.79
	2020 avg.	67.30	2.20	0.12	5.09	17.71	2.01	44.81	33.96	10.85
	2020 dry	51.07	2.20	-0.03	5.09	17.71	2.01	28.43	20.12	8.31
	2030 avg.	67.30	2.20	0.10	5.60	18.27	2.23	43.50	33.96	9.54
	2030 dry	51.07	2.20	-0.10	5.60	18.27	2.23	27.08	20.19	6.89
	2040 avg.	67.30	2.20	0.08	6.11	18.78	2.47	42.22	33.96	8.26
	2040 dry	51.07	2.20	-0.17	6.11	18.78	2.47	25.74	20.19	5.55
Arkansas-White-Red	1985 avg.	63.70	3.60	0.10	1.40	7.50	1.34	57.16	46.17	10.99
	2000 avg.	63.70	3.17	0.13	1.50	8.91	1.97	54.62	46.17	8.45
	2000 dry	39.98	3.17	0.13	1.50	8.91	1.97	30.90	19.11	11.79
	2010 avg.	63.70	2.88	0.15	1.56	9.32	2.27	53.58	46.17	7.41
	2010 dry	39.98	2.88	0.15	1.56	9.32	2.27	29.86	19.11	10.75
	2020 avg.	63.70	2.59	0.17	1.63	9.71	2.52	52.59	46.17	6.42
	2020 dry	39.98	2.59	0.17	1.63	9.71	2.52	28.88	19.11	9.77
	2030 avg.	63.70	2.30	0.20	1.70	10.02	2.81	51.67	46.17	5.50
	2030 dry	39.98	2.30	0.20	1.70	10.02	2.81	27.96	19.11	8.85
	2040 avg.	63.70	2.00	0.22	1.77	10.30	3.13	50.72	46.17	4.55
	2040 dry	39.98	2.00	0.22	1.77	10.30	3.13	27.01	19.11	7.90
Texas-Gulf	1985 avg.	35.90	3.10	0.00	1.80	4.55	1.49	31.16	22.92	8.24
	2000 avg.	35.90	3.10	0.00	1.87	5.40	2.23	29.51	22.92	6.59
	2000 dry	19.77	3.10	0.00	1.87	5.40	2.23	13.38	10.77	2.61
	2010 avg.	35.90	3.10	0.00	1.91	5.64	2.54	28.91	22.92	5.99
	2010 dry	19.77	3.10	0.00	1.91	5.64	2.54	12.78	10.77	2.01
	2020 avg.	35.90	3.10	0.00	1.96	5.87	2.81	28.36	22.92	5.44
	2020 dry	19.77	3.10	0.00	1.96	5.87	2.81	12.23	10.77	1.46
	2030 avg.	35.90	3.10	0.00	2.00	6.06	3.10	27.84	22.92	4.92
	2030 dry	19.77	3.10	0.00	2.00	6.06	3.10	11.72	10.77	0.95
	2040 avg.	35.90	3.10	0.00	2.04	6.23	3.40	27.33	22.92	4.41
	2040 dry	19.77	3.10	0.00	2.04	6.23	3.40	11.20	10.77	0.43

Notes:

See last page of the table.

Table 4.1--Generalized water budget for average and dry years, 1985 to 2040, by water resources region (continued)

Water resource region	Rainfall Condition[1]	Renewable water supply[2]	Ground-water overdraft[3]	Imports or exports[4]	Reservoir net evaporation[5]	Offstream consumptive use[6] Agriculture	Offstream consumptive use[6] Non-agriculture	Average stream outflow[7]	Instream flow requirement[8]	Surplus or deficit[9]
		billion gallons per day								
Rio Grande	1985 avg.	5.00	0.00	0.10	0.80	1.88	0.17	2.25	2.29	-0.04
	2000 avg.	5.00	0.00	0.10	0.80	2.24	0.26	1.80	2.29	-0.49
	2000 dry	4.09	0.00	0.10	0.80	2.24	0.26	0.89	1.50	-0.61
	2010 avg.	5.00	0.00	0.10	0.80	2.34	0.29	1.66	2.29	-0.63
	2010 dry	4.09	0.00	0.10	0.80	2.34	0.29	0.76	1.50	-0.74
	2020 avg.	5.00	0.00	0.10	0.80	2.44	0.32	1.54	2.29	-0.75
	2020 dry	4.09	0.00	0.10	0.80	2.44	0.32	0.63	1.50	-0.87
	2030 avg.	5.00	0.00	0.10	0.80	2.52	0.34	1.44	2.29	-0.85
	2030 dry	4.09	0.00	0.10	0.80	2.52	0.34	0.54	1.50	-0.96
	2040 avg.	5.00	0.00	0.10	0.80	2.59	0.35	1.36	2.29	-0.93
	2040 dry	4.09	0.00	0.10	0.80	2.59	0.35	0.45	1.50	-1.05
Upper Colorado	1985 avg.	12.30	0.00	-0.60	1.70	1.79	0.31	7.90	7.95	-0.05
	2000 avg.	12.30	0.00	-0.70	1.70	2.13	0.46	7.31	7.95	-0.64
	2000 dry	9.67	0.00	-0.70	1.70	2.13	0.46	4.68	3.69	0.99
	2010 avg.	12.30	0.00	-0.77	1.70	2.23	0.54	7.06	7.95	-0.89
	2010 dry	9.67	0.00	-0.77	1.70	2.23	0.54	4.43	3.69	0.74
	2020 avg.	12.30	0.00	-0.83	1.70	2.32	0.61	6.84	7.95	-1.11
	2020 dry	9.67	0.00	-0.83	1.70	2.32	0.61	4.21	3.69	0.52
	2030 avg.	12.30	0.00	-0.90	1.70	2.40	0.68	6.62	7.95	-1.33
	2030 dry	9.67	0.00	-0.90	1.70	2.40	0.68	3.99	3.69	0.30
	2040 avg.	12.30	0.00	-0.97	1.70	2.46	0.77	6.39	7.95	-1.56
	2040 dry	9.67	0.00	-0.97	1.70	2.46	0.77	3.77	3.69	0.08
Lower Colorado[13]	1985 avg.	11.20	2.10	-3.70	3.60	3.80	0.60	1.60	6.86	-5.26
	2000 avg.	11.20	2.10	-3.60	3.60	4.54	0.91	0.65	6.86	-6.21
	2000 dry	8.79	2.10	-3.60	3.60	4.54	0.91	-1.75	3.36	-5.11
	2010 avg.	11.20	2.10	-3.53	3.60	4.75	1.01	0.41	6.86	-6.45
	2010 dry	8.79	2.10	-3.53	3.60	4.75	1.01	-2.00	3.36	-5.36
	2020 avg.	11.20	2.10	-3.47	3.60	4.95	1.11	0.18	6.86	-6.68
	2020 dry	8.79	2.10	-3.47	3.60	4.95	1.11	-2.23	3.36	-5.59
	2030 avg.	11.20	2.10	-3.40	3.60	5.10	1.20	0.00	6.86	-6.86
	2030 dry	8.79	2.10	-3.40	3.60	5.10	1.20	-2.40	3.36	-5.76
	2040 avg.	11.20	2.10	-3.32	3.60	5.25	1.27	-0.14	6.86	-7.00
	2040 dry	8.79	2.10	-3.32	3.60	5.25	1.27	-2.54	3.36	-5.90

Notes:

See last page of the table.

Table 4.1--Generalized water budget for average and dry years, 1985 to 2040, by water resources region (continued)

Water resource region	Rainfall Condition[1]	Renewable water supply[2]	Ground-water overdraft[3]	Imports or exports[4]	Reservoir net evaporation[5]	Offstream consumptive use[6] Agriculture	Offstream consumptive use[6] Non-agriculture	Average stream outflow[7]	Instream flow requirement[8]	Surplus or deficit[9]
		billion gallons per day								
Great Basin	1985 avg.	8.30	0.00	0.00	0.20	3.11	0.40	4.60	3.39	1.21
	2000 avg.	8.30	0.00	0.00	0.20	3.71	0.61	3.79	3.39	0.40
	2000 dry	7.02	0.00	0.00	0.20	3.71	0.61	2.51	2.49	0.02
	2010 avg.	8.30	0.00	0.00	0.20	3.87	0.67	3.55	3.39	0.16
	2010 dry	7.02	0.00	0.00	0.20	3.87	0.67	2.28	2.49	-0.21
	2020 avg.	8.30	0.00	0.00	0.20	4.04	0.73	3.33	3.39	-0.06
	2020 dry	7.02	0.00	0.00	0.20	4.04	0.73	2.05	2.49	-0.44
	2030 avg.	8.30	0.00	0.00	0.20	4.16	0.78	3.15	3.39	-0.24
	2030 dry	7.02	0.00	0.00	0.20	4.16	0.78	1.88	2.49	-0.61
	2040 avg.	8.30	0.00	0.00	0.20	4.28	0.82	3.00	3.39	-0.39
	2040 dry	7.02	0.00	0.00	0.20	4.28	0.82	1.72	2.49	-0.77
Pacific Northwest	1985 avg.	291.00	0.00	0.00	0.60	9.76	0.82	279.82	214.00	65.82
	2000 avg.	291.00	0.00	0.00	0.60	11.64	1.08	277.68	214.00	63.68
	2000 dry	245.52	0.00	0.00	0.60	11.64	1.08	232.19	174.60	57.59
	2010 avg.	291.00	0.00	0.00	0.60	12.17	1.19	277.04	214.00	63.04
	2010 dry	245.52	0.00	0.00	0.60	12.17	1.19	231.55	174.60	56.95
	2020 avg.	291.00	0.00	0.00	0.60	12.68	1.30	276.42	214.00	62.42
	2020 dry	245.52	0.00	0.00	0.60	12.68	1.30	230.94	174.60	56.34
	2030 avg.	291.00	0.00	0.00	0.60	13.08	1.39	275.93	214.00	61.93
	2030 dry	245.52	0.00	0.00	0.60	13.08	1.39	230.45	174.60	55.85
	2040 avg.	291.00	0.00	0.00	0.60	13.45	3.82	273.13	214.00	59.13
	2040 dry	245.52	0.00	0.00	0.60	13.45	3.82	227.65	174.60	53.05
California	1985 avg.	86.90	1.40	3.70	0.50	20.33	1.82	69.35	32.61	36.74
	2000 avg.	86.90	1.22	3.70	0.50	24.27	2.89	64.16	32.61	31.55
	2000 dry	42.72	1.22	3.70	0.50	24.27	2.89	19.98	26.07	-6.09
	2010 avg.	86.90	1.10	3.70	0.50	25.37	3.20	62.63	32.61	30.02
	2010 dry	42.72	1.10	3.70	0.50	25.37	3.20	18.45	26.07	-7.62
	2020 avg.	86.90	0.98	3.70	0.50	26.43	3.46	61.18	32.61	28.57
	2020 dry	42.72	0.98	3.70	0.50	26.43	3.46	17.00	26.07	-9.07
	2030 avg.	86.90	0.86	3.70	0.50	27.27	3.67	60.02	32.61	27.41
	2030 dry	42.72	0.86	3.70	0.50	27.27	3.67	15.84	26.07	-10.23
	2040 avg.	86.90	0.74	3.70	0.50	28.04	3.82	58.98	32.61	26.37
	2040 dry	42.72	0.74	3.70	0.50	28.04	3.82	14.80	26.07	-11.27

Notes:

See last page of the table.

Table 4.1--Generalized water budget for average and dry years, 1985 to 2040, by water resources region (continued)

Water resource region	Rainfall Condition[1]	Renewable water supply[2]	Ground-water overdraft[3]	Imports or exports[4]	Reservoir net evaporation[5]	Offstream consumptive use[6] Agriculture	Offstream consumptive use[6] Non-agriculture	Average stream outflow[7]	Instream flow requirement[8]	Surplus or deficit[9]
		billion gallons per day								
Total contiguous U.S.[14]	1985 avg.	1391.90	12.40	-1.60	15.10	74.83	17.90	1294.87	1043.18	251.69
	2000 avg.	1391.90	11.79	-1.60	15.60	88.95	26.12	1271.42	1043.18	228.24
	2000 dry	1010.65	11.79	-1.60	15.60	88.95	26.12	890.17	784.98	105.19
	2010 avg.	1391.90	11.38	-1.60	15.93	93.01	29.61	1263.13	1043.18	219.95
	2010 dry	1010.65	11.38	-1.60	15.93	93.01	29.61	881.88	784.98	96.90
	2020 avg.	1391.90	10.97	-1.60	16.17	96.91	32.61	1255.58	1043.18	212.40
	2020 dry	1010.65	10.97	-1.60	16.17	96.91	32.61	874.34	784.98	89.36
	2030 avg.	1375.77	10.56	-1.60	16.60	99.96	35.72	1232.45	1031.03	201.42
	2030 dry	1010.65	10.56	-1.60	16.60	99.96	35.72	867.33	784.98	82.35
	2040 avg.	1391.90	10.14	-1.60	16.93	102.78	41.25	1239.49	1043.18	196.31
	2040 dry	1010.65	10.14	-1.60	16.93	102.78	41.25	858.24	784.98	73.26

Notes:

1. Average condition represents the flows in a "normalized" year, when the amount of annual precipitation is the long-term average (the precipitation that is exceeded 50 percent of the time). The dry condition is the normalized flow when the amount of annual precipitation is exceeded 80 percent of the time.
2. Renewable supply is the precipitation that reaches aquifers or that runs off into surface water supplies. It is estimated by taking measured instream flows, subtracting other supplies (overdrafts and imports), and adding depletions (consumptive use, net reservoir evaporation, and exports).
3. Groundwater overdrafts are quantities of water withdrawn from aquifers in excess of the recharge volume. These estimates were obtained from Anon. (1984, page 243), cited by Foxworthy and Moody (1986, table 7).
4. Exports are shown in the table as a negative number. The data were taken from Petch (1985), cited by Foxworthy and Moody (1986, table 8).
5. Data for net reservoir evaporation were taken from Foxworthy and Moody (1986, table 7).
6. Consumptive use estimates for agriculture are the sum of numbers in tables A-14 and A-18. Consumptive use estimates for non-agriculture are the sum of numbers from tables A-13, A-15, A-16, and A-17.
7. Average stream outflow are from Graczyk and others (1986).
8. Instream flow requirements for average years are the flows needed for optimal fish and wildlife habitat. Data are from Water Resources Council (1978). Instream flow requirements for good survival habitat in dry years are assumed to be 60 percent of mean natural flow in the average year for New England, Mid-Atlantic, South Atlantic-Gulf, Great Lakes, Ohio, Tennessee, Upper and Lower Mississippi and the Pacific Northwest regions. In the other regions, the instream flow requirements for good survival habitat in dry years are assumed to be 30 percent of mean natural flow in the average year (Flickinger 1987).
9. A surplus exists if the average stream outflow exceeds the instream flow requirement. A deficit exists if the instream flow requirement exceeds the average stream outflow.
10. The estimates for the Ohio water resource region are exclusive of outflows from the Tennessee region.
11. The estimates for the Upper Mississippi water resource region are exclusive of outflows from the Missouri region.
12. The estimates for the Lower Mississippi water resource region represent conditions in all the upstream regions (Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red regions.
13. The estimates for the Lower Colorado water resources region represent conditions in both the Upper and Lower Colorado regions
14. The total for the contiguous U.S. includes data for the lower 48 States. Information on instream flow requirements was not available for the Hawaii, Alaska, not Caribbean regions.

SOURCE: After Flickinger (1987, table 28b) and Foxworthy and Moody (1986, table 7).

Plentiful Supplies

Water surpluses exist in all the regions east of the Great Plains and the Pacific Northwest, even in dry years, through 2040. In most cases, the surplus in an average rainfall year exceeds 10 percent of the instream flow requirement for optimal habitat; in more than half the regions, the surplus exceeds 25 percent of the instream flow requirement. In dry years, surpluses still exist in all regions east of the Great Plains and the Pacific Northwest. The surpluses in dry years still exceed instream flow requirements for good survival habitat by at least 10 percent through 2040.

The existence of surpluses out through 2040 in these regions suggests that there is plenty of water available, on a regional basis, even in abnormally dry years. The surpluses provide a comfortable cushion of flow volume that guarantees continued abundance of both warm and cold water fisheries, assuming of course, that water quality is not limiting.

Although the surpluses are heartening, on a regional basis, there will still be reaches of rivers and seasons of the year, when flows diminish to the point where good survival habitat is threatened. U.S. Forest Service (1981) contained a more detailed analysis of flow depletions than presented in this report. The results of that analysis show that even in many of the regions which have regional surpluses, there will be certain river drainages where low flows fall to less than 10 percent of the mean annual flow for several months each year. Extended periods of flows that low, coupled with the quantities of oxygen-demanding wastes formerly discharged into the streams in the 1950s and 1960s, resulted in the near-absence of sport fish in many of those drainages. Even non-sport fish were not prevalent. With the reduction in the quantity of oxygen-demanding wastes discharged to these streams as a result of the Clean Water Act, fish populations have expanded in many of these streams to the point where viable sport fish populations have emerged.

Because ample flows exist in all these water resource regions, there is no inconsistency between the demand and supply projections. If both projections were plotted on same axes, they would not intersect. Consequently, the lesser of the two curves--the demand projections--can be viewed as equilibrium projections. The excess supplies are not needed to satisfy current or projected needs. If water were produced and priced like a manufactured product, production output would be reduced to the levels demanded through time. But because of the nature of the streamflow "production" process, cutbacks are not possible.

Shortages

Lower Colorado Region--In years of average rainfall now, the Lower Colorado water resource region faces significant deficits for water. The deficits in an average year amount to nearly the same level as the instream flow requirement for optimal fish and wildlife habitat. In dry years, the deficits are roughly 160 percent of the instream flow requirement for good survival habitat. The deficits are between 250 and 300 percent of the groundwater overdraft level in the region. Of all the regions in the U.S., this one has the most severe

problems now. Projections of recent trends suggest it will also have the most significant problems in the future.

In 1985, irrigation consumed 86 percent of the 4.4 bgd average consumption in the Lower Colorado region, table 4.2. The deficit in the average year exceeds daily consumption by 850 million gallons per day. By 2040, irrigation consumption drops to 80 percent of the 6.5 bgd consumed. Conservation measures likely to be adopted will retard growth in the deficit over the projection period--consumption is projected to increase 2.1 bgd over the projection period while the deficit increased only 1.7 bgd in the mean year (0.8 bgd in the dry year). The projected water deficit in 2040 in an average rainfall year is 47 percent larger than the renewable supply (58 percent in the dry year).

Supply augmentation measures at the scale needed to eliminate the deficit are not likely to be implemented. The measures available are vegetation management, construction of snow-trapping structures, and weather modification. All have been demonstrated feasible for increasing or changing the season of runoff over a local area. But none has been implemented over a wide enough geographic area to evaluate their ability to make a significant contribution to reducing the projected deficit. However, the feasibility studies have shown that implementing such measures, at the scale needed to eliminate the deficit, will create regional environmental impacts on visual amenities and high-altitude vegetation far in excess of the impact level heretofore deemed acceptable. Thus, measures to increase supplies are unlikely to make a significant contribution to reducing the deficit. While supply management practices, such as storing runoff in a wet year for use in drier years, do make a significant contribution to satisfying demands, additional reservoir construction on the scale necessary to eliminate the deficit is not likely either. Imports are 19 percent of renewable supply, but significant increases are unlikely given the interbasin agreements currently in place that regulate flows on the Lower Colorado River.

Groundwater overdrafts are presently 345 percent of non-irrigation consumption needs. Overdrafts are a short-term expedient for meeting current demands, but eventually will exacerbate the problem. So using additional overdrafts to cure the deficit is not feasible.

Consequently, only two inescapable conclusions remain. Either the wildlife and fish habitat and recreation potential dependent on instream flows that are at least 30 percent of the mean annual flow level (good survival habitat) will be sacrificed or consumption of water by offstream uses will have to be drastically curtailed.

The instream flows in 1987 are already less than 25 percent of the flows needed for optimal habitat. Projections of increased demand drive streamflow to less than 10 percent of optimal by 2000 in the average year and to negative streamflows in dry years by 2000 (possible only by drawing down reservoir storage). By 2040, if recent trends in use continue, negative flows will occur in the mean year as well.

Table 4.2--Water consumption in the Lower Colorado water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
	----------	----------	----------	----------	----------	million gallons per day	----------	----------	----------	----------	----------
Irrigation	3395	3100	4700	5700	4300	3791	4527	4732	4930	5085	5230
Municipal central supplies	110	150	190	240	390	338	564	622	672	708	728
Industrial self-supplies	32	51	100	190	150	164	201	227	254	280	307
Thermoelectric steam cooling	7	15	36	47	49	73	117	141	159	183	212
Domestic self-supplies	6	5	17	27	27	22	23	24	24	25	25
Livestock watering	12	16	28	47	11	13	13	14	15	15	16
Total Consumption	3561	3337	5071	6251	4927	4402	5445	5760	6054	6296	6517
Deficit - Mean Year[1]						5260	6210	6450	6680	6860	7000
Deficit - Dry Year[2]							5110	5360	5590	5760	5900

Notes:

See table 4.3, below

Table 4.3--Water consumption in the Rio Grande water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
	----------	----------	----------	----------	----------	million gallons per day	----------	----------	----------	----------	----------
Irrigation	3402	3900	3000	3200	2100	1851	2211	2311	2408	2484	2554
Municipal central supplies	124	110	150	190	140	121	202	223	241	254	261
Thermoelectric steam cooling	4	11	17	20	11	16	26	32	36	41	47
Livestock watering	13	68	36	37	26	31	32	33	35	36	37
Industrial self-supplies	31	46	97	55	13	14	17	20	22	24	27
Domestic self-supplies	6	7	13	17	18	15	16	16	17	17	17
Total Consumption	3581	4142	3313	3519	2308	2050	2504	2635	2758	2856	2943
Deficit - Mean Year[1]						400	490	630	750	850	930
Deficit - Dry Year[2]							610	740	870	960	1050

Notes:

1. The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 1 and 8, table 4.1).
2. The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 1 and 8, table 4.1).

The magnitude of the deficit and magnitude of conservation measures implied by recent historical trends in consumption suggest that major new conservation measures will be necessary to cope with the unrelenting increase in deficits. Clearly, strong measures must be taken to deal with the deficit if long-term adverse impacts are to be avoided. Just as clearly, recent trends in the growth of demand for water will have to be reduced to reduce the deficit. Because irrigation is the largest water consumer in the Lower Colorado region and because irrigation water has the lowest price, it will likely be the use that bears the brunt of the demand reduction. Reductions have already begun. Irrigation consumption peaked in 1975 at 5.7 bgd. Since then, consumption has declined by 33 percent to 3.7 bgd, table 4.2. Further reductions will be necessary to bring supplies and demand into equilibrium. Compared to the 1980 use level, municipal demands have dropped 13 percent to 338 mgd in 1985. Whether or not this reduction is the beginning of a long-term reduction in municipal use will not be known until after the 1990 water use data is collected and analyzed.

Prices for water are likely to rise as available supplies of water are rationed by market forces to their highest and best uses. Active markets for water rights have emerged in the States comprising the Lower Colorado region, and especially in Colorado. Institutional adjustments to provide additional freedom in buying and selling water rights are likely to occur to facilitate demand adjustments. Prices will climb as impediments to market functioning are eliminated. Many irrigators will find it quite profitable to liquidate some of their water assets by selling rights to municipal water users. Lease-back arrangements may become a popular method to ease land out of agricultural production.

In summary, water consumption in the Lower Colorado region will need to decline to bring it into long-term equilibrium with available supplies. No other single factor, nor combination of factors, has the potential for significantly reducing the water supply deficit. Prices for water are likely to rise substantially in the Lower Colorado region as shortages continue. The price increases will help bring demand and supply into equilibrium. The ultimate schedule of prices for water cannot be reliably projected at this time, but the long-term equilibrium quantity resulting from the price adjustments will probably be close to current supply levels.

<u>Rio Grande Region</u>--The Rio Grande region also has a current deficit and projected increases in deficits out to 2040. But in contrast to the Lower Colorado region where the deficit exceeds current and projected future consumption levels, the deficit in the Rio Grande region is only between 20 percent (today) and 32 percent (in 2040) of consumption levels in the average year, table 4.3. Deficits in dry years are not much worse--24 percent of projected use in 2000 and 36 percent in 2040.

Groundwater overdrafts are not used and imports are low--2 percent of renewable supply. Neither offer much hope for reducing the deficit. The region to the west is the Lower Colorado where interbasin transfers are strictly controlled and increasing exports would encounter insurmountable institutional barriers. The Arkansas-White-Red basin is to the north and east; but the closest drainages to the Rio Grande are not reliable sources of water for exports

either. Using additional groundwater to eliminate the deficit is not likely because available aquifers are not capable of withstanding significant increases in withdrawals nor short-term overdrafts. Additional reservoir developments of the magnitude needed to eliminate the deficit are not feasible either given todays conditions.

As in the Lower Colorado region, the greatest potential for reducing the deficit lies in curtailing consumption. If irrigation demands can be held at current levels throughout the projection period, three-fourths of the deficit can be eliminated. Irrigation demand peaked at 3.2 bgd in 1975 and has since declined 42 percent to the 1985 level of 1.85 bgd. If an additional 12 percent decline in irrigation use can be attained by 2000, the deficit in the mean year will be converted into a surplus of 92 mgd and in the dry year, the deficit would be a negligible 28 mgd--1 percent of total consumption. Future deficits would likewise be negligible in the mean year and only a minor problem in dry years (about 5 percent of total consumption in 2040).

In summary, minor increases in water conservation measures for irrigation followed by holding the line against further increases in irrigation water usage will eliminate the deficits in the Rio Grande region by 2000 and for the remainder of the projection period. Projections of recent trends for non-agricultural water usage can be accommodated within this scenario. Equilibrium water usage will progress from 2.05 bgd in 1985 to 2.02 bgd in 2040--essentially the constant supply projection.

Upper Colorado Region--The Upper Colorado region had a negligible deficit in 1985 of 50 mgd, table 4.4. But demand projections indicate that deficits will rise to 1.56 bgd by 2040. The situation in this region is interesting, because the dry year assumptions project surpluses through 2040. The reason is the difference in instream flows necessary for optimal versus good survival habitat for fish and wildlife. The difference between those two instream flow assumptions makes the difference between the deficits and surpluses. The projected deficits are between 10 and 25 percent of average stream outflows.

In the Upper Colorado region, the question whether or not to reduce the deficit depends upon the degree to which anglers, hunters, and recreationists are content with less than optimal instream flows. If they are content with minor departures from the optimum, little needs to be done between now and 2020. If, on the other hand, departures from the optimum cause significant reductions in benefits from instream flows, then some moderate demand reduction measures can be taken. For example, if irrigation water usage can be held at the 1985 level through 2040, half the projected deficits in the mean year can be eliminated. The remaining deficits would only be 11 percent of the optimal instream flow--probably a tolerable reduction from the optimum because the average rainfall is expected to be exceeded (and wash away the deficit) 5 years in 10. The equilibrium flow rates will likely lie close to the long-term supply projection. Vegetation management, snow-trapping structures, and weather modification many be able to make a contribution to eliminating a deficit of this magnitude. They are already being practiced in eastern headwater watersheds in this region.

Table 4.4--Water consumption in the Upper Colorado water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
	million gallons per day										
Irrigation	3505	3200	4000	1500	2000	1763	2105	2201	2293	2365	2433
Thermoelectric steam cooling	8	18	22	60	130	194	312	373	421	484	561
Industrial self-supplies	5	8	21	27	63	69	84	95	106	118	129
Municipal central supplies	10	14	19	26	41	36	59	65	71	74	77
Livestock watering	7	10	17	14	22	26	27	28	30	30	31
Domestic self-supplies	2	2	3	3	17	8	8	8	8	8	8
Total Consumption	3538	3252	4082	1630	2273	2096	2595	2771	2929	3080	3238
Deficit - Mean Year[1]						50	640	890	1110	1330	1560
Deficit - Dry Year[2]							(990)[3]	(740)	(520)	(300)	(80)

Notes:

1. The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 1 and 8, table 4.1).
2. The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 1 and 8, table 4.1).
3. Numbers in parentheses are negative deficits, that is, surpluses.

Great Basin region--The Great Basin is projected to have surpluses in the average year through 2010, a negligible deficit in 2020 (3 percent of average stream outflow), and deficits necessitating a response beginning in 2030, table 4.5. Even in the dry year, surpluses are projected for 2000. Significant deficits do not emerge until 2010 in dry years, and then they are approximately three times the magnitude of deficits in average years.

Holding irrigation water usage at 1985 levels would more than wipe out the projected deficits through 2040, even in dry years. In fact, the projections indicate that irrigation water usage could be allowed to increase by 400 mgd through 2040 and supplies would still be adequate to meet demands even in dry years. So in this region, managing growth at a lower rate than prevalent since 1960 will suffice to assure adequate water supplies in dry years. The equilibrium between supply and demand will follow the demand projections out to 2020 when deficits emerge. At that point, the equilibrium projection shifts to the supply line to 2040.

California Region--California has abundant water supplies in average years, table 4.6. Surpluses in years of average rainfall will exceed total consumption to 2010 and represent 83 percent of annual consumption in 2040. However, during dry years, significant deficits emerge. The deficit in 2000 during a dry year amounts to 30 percent of average stream outflow and grows by 2040 to 76 percent of average stream outflow in dry years.

California is one of the leaders in moving water from locations of plentiful supply to areas where shortages are expected. Aqueducts whose length and capacity are unchallenged in this Nation move water from drainages in the Sierras to the San Joaquin valley and Los Angeles metropolitan areas. Imports from the Lower Colorado region to the Los Angeles metropolitan area also occur. So of all the regions, California typifies the region where imbalances between local demands and local supplies have been solved using structural methods. But additional structural methods are unlikely to completely solve the deficit problem in dry years. The benefit stream from solving dry-year deficits is too irregular to justify additional structural solutions to the deficit problem given the surpluses normally expected at least half the time.

The tradeoffs in California during dry years are similar to the ones outlined earlier in the Upper Colorado region--the extent to which demands in dry years should be curtailed to preserve good survival habitat for fish and wildlife and other instream water uses. If agricultural water usage in California can be held to 1985 levels, this action alone would eliminate two-thirds of the deficit in dry years. Further, this action would reduce the deficit to 14 percent of the instream flow requirement in dry years. With some limited additional conservation practices in dry years to reduce water consumption another 5 to 10 percent, limited detrimental impacts to good survival habitat could be tolerated 2 years in 10. Vegetation management, snow-trapping structures, and weather modification may be able to help mitigate the detrimental impacts to instream habitats in this region too.

The equilibrium projection in California will follow the demand line in the average year. Equilibrium in a dry year will dip somewhat as demands are curtailed in response to more limited supplies of water.

Table 4.5--Water consumption in the Great Basin water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
	million gallons per day										
Irrigation	3300	3000	2900	3400	3500	3086	3684	3852	4013	4139	4257
Municipal central supplies	67	69	140	140	310	269	448	494	534	563	579
Industrial self-supplies	9	36	62	63	100	109	134	151	169	187	204
Thermoelectric steam cooling	2	2	6	6	6	9	14	17	19	22	26
Livestock watering	19	16	21	20	17	20	21	22	23	24	24
Domestic self-supplies	8	15	13	6	14	10	11	11	11	12	12
Total Consumption	3405	3138	3142	3635	3947	3504	4312	4548	4770	4946	5102
Deficit - Mean Year[1]						(1210)[3]	(400)	(160)	60	240	390
Deficit - Dry Year[2]							(20)	210	440	610	770

Notes:

See Table 4.6, below

Table 4.6--Water consumption in the California water resource region, 1960 to 1985, with projections of of consumption and water deficits to 2040

	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
	million gallons per day										
Irrigation	13000	16000	21000	21000	23000	20278	24212	25313	26371	27201	27975
Municipal central supplies	370	1300	1400	1500	1700	1473	2458	2711	2929	3086	3175
Industrial self-supplies	80	110	170	180	190	208	254	288	321	355	389
Thermoelectric steam cooling	17	18	24	32	41	61	98	118	133	153	177
Domestic self-supplies	120	51	73	76	84	73	77	79	80	81	82
Livestock watering	66	45	50	54	47	56	57	60	63	65	66
Total Consumption	13653	17524	22717	22842	25062	22150	27156	28569	29898	30941	31864
Deficit - Mean Year[1]						(36740)[3]	(31550)	(30020)	(28570)	(27410)	(26370)
Deficit - Dry Year[2]							6090	7620	19070	10230	11270

Notes:

1. The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 1 and 8, table 4.1).
2. The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 1 and 8, table 4.1).
3. The numbers in parentheses are negative deficits, that is, surpluses.

Summary--Four common themes have emerged from the analysis of surpluses and deficits in the Rio Grande, Upper and Lower Colorado, Great Basin, and California water resource regions.

The first is that the impetus to resolve the deficits will come from a desire to mitigate adverse impacts on fish and wildlife habitat and recreation use caused by low instream flows. Fishing and water-based recreation are both extremely popular activities. Adequate instream flows are essential for both. If benefits from these activities decline, users will demand that the responsible public officials take action or litigation will likely follow. Public sentiment is strong to preserve habitat and recreational opportunities.

The second theme is that because irrigation is the predominant consumptive use, accounting for more than three-fourths of all use in each region, as well as the lowest-value offstream use in all the regions, eliminating the deficits will require some reduction in the projected rates of growth in irrigation water usage. Experts have recently concluded that irrigated crop production is on the verge of a major shift away from historical trends in acres irrigated and water usage (Department of Agriculture 1987). The RCA Appraisal (Department of Agriculture 1987) contains three scenarios projecting cropland and pasture production to 2030. If the intermediate scenario happens, the acreage of cropland irrigated will drop 19 million acres between 1982 and 2030 to 44 million acres. Irrigation water usage will drop commensurately. A significant portion of the decline will occur in the five regions where shortages are projected. Changes in irrigation practices outlined in Department of Agriculture (1987, Chapter 7) will lead to additional reductions in total irrigation water usage. So it appears that reductions in irrigation water usage will make a significant contribution to eliminating water supply deficits over the next 40 to 50 years.

The third theme is that non-structural approaches, such as modifications in water rights institutions and freer functioning of water markets, will play the dominant role in solving water supply deficits. The days of using structural approaches as the dominant way to reducing deficits are past. For example, proposals for new reservoirs are encountering increasing amounts of public opposition in spite of the support by local agricultural interests. The high-quality dam sites have long since been used. The potential sites remaining all have difficulties of one form or another--geological, environmental, economic, or institutional. Chapter 7 of the Appraisal contains an overview of non-structural changes and their potential for helping alleviate shortages.

The fourth theme is that water yield augmentation by vegetation management, building snow-trapping structures, and weather modification can help remedy small deficits. However, these techniques are unlikely to be employed as the dominant way of eliminating major deficits.

Alternative Futures

The supply/demand situations outlined in tables 4.1 to 4.6 are based upon the assumptions that changes in consumption from 1960 to 1985 are the best basis

for projecting future changes in consumption from 1990 to 2040. Alternative future scenarios about supply and demand have been developed for this report that result in changes in the surpluses and deficits reported in tables 4.1 to 4.6. The approach to specifying alternative futures for water was to consider two alternative rates of change in demand: demands 13 percent higher in 2000 and 20 percent higher from 2010 to 2040; and demands 13 percent lower in 2000 and 20 percent lower from 2010 to 2040. For other resources, supply trend increases 20 percent above and below the long-term trend were also evaluated. But because no trend exists in the long-term renewable supply of water, and because 20 percent increases or decreases in renewable supplies within 15 years were judged implausible for water, the supply side analyses of alternative futures were ignored.

A Future Where Demand is 20 Percent Higher in 2040 than Projected

The alternative futures for demand lead to shifts in surpluses and deficits, table 4.7. All the regions that had surpluses under the baseline Assessment demand assumption continue to have surpluses even if demand is increased 20 percent, except for the Texas-Gulf region. In dry years in the Texas-Gulf region, deficits begin in 2020 and continue to 2040.

In the Great Basin, the deficits appear earlier. Under the Assessment baseline projection, deficits appeared in 2010 for the dry year and 2020 for the average rainfall year. If demand is 20 percent higher than projected, the first deficit appears only a decade from now in 2000 under both rainfall conditions. In addition, the deficits are much larger--130 percent (2040 dry) to 430 percent (2010 dry).

In California, deficits still do not appear in years of average rainfall, even if demand is 20 percent greater than expected. In dry years, the deficits are 2 percent (2010) to 57 percent (2040) larger.

A Future Where Demand is 20 Percent Lower in 2040 than Projected

Lower demand seems much more likely to occur than increased demand, given the projected decline in irrigated acreage of 19 million acres in Department of Agriculture (1987). Demand reductions generally postpone the beginning of deficits and reduce their intensity, table 4.7.

In the Rio Grande region, where a small 40 mgd deficit occurs now in average years, a 20 percent drop in demand would postpone until 2010 the onset of deficits in average rainfall years. A small deficit would occur by 2000 in dry years. The reduction in demand reduces the magnitude of the deficits--they are roughly one-third the level originally projected.

In the Upper Colorado region, reducing demand 20 percent eliminates deficits in dry years and provides good survival habitat. But a 20-percent reduction in demand still is not enough to eliminate the deficits and provide optimal habitat in the average-rainfall year. The deficits in the average year are only 40 percent of the deficits under baseline demands, but the demand reduction is still not enough to provide optimal fish and wildlife habitat and optimal instream flows for recreation. On the other hand, the deficits that

Table 4.7--Surpluses and deficits resulting from alternative demand futures, by water resource regions

Water resource region	Rainfall Condition	Surpluses or deficits Projected -20 percent	Projected Demand[1]	Projected +20 percent
		---------billion gallons per day---------		
New England	1985 avg.	7.83	7.76	7.70
	2000 avg.	7.72	7.63	7.54
	2000 dry	15.17	15.08	14.99
	2010 avg.	7.69	7.58	7.48
	2010 dry	15.14	15.03	14.93
	2020 avg.	7.65	7.54	7.43
	2020 dry	15.10	14.99	14.88
	2030 avg.	7.62	7.50	7.38
	2030 dry	15.07	14.95	14.83
	2040 avg.	7.59	7.47	7.34
	2040 dry	15.04	14.92	14.79
Mid-Atlantic	1985 avg.	25.37	25.03	24.68
	2000 avg.	24.77	24.27	23.77
	2000 dry	14.23	13.74	13.24
	2010 avg.	24.53	23.97	23.41
	2010 dry	14.00	13.44	12.88
	2020 avg.	24.32	23.71	23.10
	2020 dry	13.79	13.18	12.57
	2030 avg.	24.12	23.46	22.80
	2030 dry	13.59	12.93	12.27
	2040 avg.	23.92	23.21	22.50
	2040 dry	13.39	12.68	11.96
South Atlantic-Gulf	1985 avg.	19.84	18.84	17.85
	2000 avg.	18.73	17.46	16.20
	2000 dry	21.13	19.86	18.60
	2010 avg.	18.27	16.89	15.51
	2010 dry	20.67	19.29	17.91
	2020 avg.	17.86	16.37	14.88
	2020 dry	20.26	18.77	17.28
	2030 avg.	17.46	15.87	14.29
	2030 dry	19.86	18.27	16.69
	2040 avg.	17.07	15.39	13.71
	2040 dry	19.47	17.79	16.11

Notes:

See last page of the table.

Table 4.7--Surpluses and deficits resulting from alternative demand futures, by water resource regions (continued)

Water resource region	Rainfall Condition	Surpluses or deficits Projected -20 percent	Projected Demand[1]	Projected +20 percent
		billion gallons per day		
Great Lakes	1985 avg.	10.24	9.99	9.73
	2000 avg.	9.91	9.57	9.24
	2000 dry	12.07	11.74	11.40
	2010 avg.	9.77	9.39	9.02
	2010 dry	11.93	11.56	11.19
	2020 avg.	9.64	9.23	8.83
	2020 dry	11.80	11.40	11.00
	2030 avg.	9.51	9.08	8.64
	2030 dry	11.68	11.24	10.81
	2040 avg.	9.39	8.93	8.46
	2040 dry	11.56	11.09	10.63
Ohio	1985 avg.	16.07	15.69	15.31
	2000 avg.	15.48	14.95	14.41
	2000 dry	21.15	20.62	20.09
	2010 avg.	15.17	14.57	13.96
	2010 dry	20.85	20.24	19.64
	2020 avg.	14.92	14.25	13.58
	2020 dry	20.60	19.93	19.26
	2030 avg.	14.63	13.89	13.15
	2030 dry	20.31	19.56	18.82
	2040 avg.	14.31	13.49	12.66
	2040 dry	19.98	19.16	18.34
Tennessee	1985 avg.	4.51	4.43	4.35
	2000 avg.	4.43	4.33	4.23
	2000 dry	11.77	11.67	11.57
	2010 avg.	4.38	4.27	4.16
	2010 dry	11.72	11.61	11.50
	2020 avg.	4.33	4.21	4.09
	2020 dry	11.68	11.56	11.43
	2030 avg.	4.29	4.16	4.03
	2030 dry	11.63	11.50	11.37
	2040 avg.	4.25	4.10	3.96
	2040 dry	11.59	11.45	11.30

Notes:

See last page of the table.

Table 4.7--Surpluses and deficits resulting from alternative demand futures, by water resource regions (continued)

Water resource region	Rainfall Condition	Surpluses or deficits: Projected -20 percent	Projected Demand[1]	Projected +20 percent
		---------billion gallons per day---------		
Upper Mississippi	1985 avg.	10.37	10.06	9.75
	2000 avg.	9.98	9.58	9.17
	2000 dry	16.65	16.25	15.84
	2010 avg.	9.80	9.34	8.89
	2010 dry	16.46	16.01	15.56
	2020 avg.	9.64	9.15	8.66
	2020 dry	16.31	15.82	15.33
	2030 avg.	9.47	8.94	8.40
	2030 dry	16.14	15.60	15.07
	2040 avg.	9.28	8.70	8.12
	2040 dry	15.95	15.37	14.79
Lower Mississippi	1985 avg.	105.91	104.69	103.47
	2000 avg.	103.30	101.76	100.22
	2000 dry	26.20	24.66	23.12
	2010 avg.	101.92	100.26	98.59
	2010 dry	24.82	23.16	21.49
	2020 avg.	100.59	98.81	97.04
	2020 dry	23.49	21.71	19.94
	2030 avg.	99.27	97.39	95.50
	2030 dry	22.17	20.29	18.40
	2040 avg.	97.93	95.93	93.94
	2040 dry	20.83	18.83	16.84
Souris-Red-Rainey	1985 avg.	3.54	3.52	3.49
	2000 avg.	3.52	3.49	3.46
	2000 dry	1.56	1.53	1.50
	2010 avg.	3.51	3.48	3.45
	2010 dry	1.55	1.52	1.49
	2020 avg.	3.50	3.47	3.44
	2020 dry	1.54	1.51	1.48
	2030 avg.	3.50	3.47	3.43
	2030 dry	1.54	1.51	1.47
	2040 avg.	3.49	3.46	3.43
	2040 dry	1.53	1.50	1.47

Notes:

See last page of the table.

Table 4.7--Surpluses and deficits resulting from alternative demand futures, by water resource regions (continued)

Water resource region	Rainfall Condition	Surpluses or deficits Projected -20 percent	Projected Demand[1]	Projected +20 percent
		---------billion gallons per day---------		
Missouri	1985 avg.	20.67	17.72	14.78
	2000 avg.	17.37	13.80	10.23
	2000 dry	14.91	11.34	7.78
	2010 avg.	16.05	12.28	8.52
	2010 dry	13.55	9.79	6.02
	2020 avg.	14.79	10.85	6.90
	2020 dry	12.25	8.31	4.36
	2030 avg.	13.64	9.54	5.44
	2030 dry	10.98	6.89	2.79
	2040 avg.	12.51	8.26	4.01
	2040 dry	9.80	5.55	1.30
Arkansas-White-Red	1985 avg.	12.76	10.99	9.22
	2000 avg.	10.62	8.45	6.27
	2000 dry	13.97	11.79	9.61
	2010 avg.	9.73	7.41	5.09
	2010 dry	13.07	10.75	8.43
	2020 avg.	8.87	6.42	3.98
	2020 dry	12.22	9.77	7.32
	2030 avg.	8.07	5.50	2.94
	2030 dry	11.41	8.85	6.28
	2040 avg.	7.24	4.55	1.87
	2040 dry	10.58	7.90	5.21
Texas-Gulf	1985 avg.	9.45	8.24	7.03
	2000 avg.	8.11	6.59	5.06
	2000 dry	4.14	2.61	1.09
	2010 avg.	7.63	5.99	4.36
	2010 dry	3.65	2.01	0.38
	2020 avg.	7.17	5.44	3.70
	2020 dry	3.20	1.46	-0.28
	2030 avg.	6.76	4.92	3.09
	2030 dry	2.78	0.95	-0.88
	2040 avg.	6.34	4.41	2.48
	2040 dry	2.36	0.43	-1.49

Notes:

See last page of the table.

Table 4.7--Surpluses and deficits resulting from alternative demand futures, by water resource regions (continued)

Water resource region	Rainfall Condition	Surpluses or deficits: Projected -20 percent	Projected Demand[1]	Projected +20 percent
		---------billion gallons per day---------		
Rio Grande	1985 avg.	0.37	-0.04	-0.45
	2000 avg.	0.01	-0.49	-1.00
	2000 dry	-0.11	-0.61	-1.11
	2010 avg.	-0.10	-0.63	-1.15
	2010 dry	-0.22	-0.74	-1.27
	2020 avg.	-0.20	-0.75	-1.30
	2020 dry	-0.32	-0.87	-1.42
	2030 avg.	-0.27	-0.85	-1.42
	2030 dry	-0.39	-0.96	-1.54
	2040 avg.	-0.34	-0.93	-1.52
	2040 dry	-0.46	-1.05	-1.64
Upper Colorado	1985 avg.	0.37	-0.05	-0.46
	2000 avg.	-0.13	-0.64	-1.16
	2000 dry	1.51	0.99	0.47
	2010 avg.	-0.34	-0.89	-1.45
	2010 dry	1.30	0.74	0.19
	2020 avg.	-0.52	-1.11	-1.69
	2020 dry	1.11	0.52	-0.06
	2030 avg.	-0.71	-1.33	-1.95
	2030 dry	0.92	0.30	-0.31
	2040 avg.	-0.91	-1.56	-2.20
	2040 dry	0.72	0.08	-0.57
Lower Colorado	1985 avg.	-4.38	-5.26	-6.14
	2000 avg.	-5.12	-6.21	-7.29
	2000 dry	-4.02	-5.11	-6.20
	2010 avg.	-5.30	-6.45	-7.60
	2010 dry	-4.20	-5.36	-6.51
	2020 avg.	-5.47	-6.68	-7.89
	2020 dry	-4.38	-5.59	-6.80
	2030 avg.	-5.60	-6.86	-8.12
	2030 dry	-4.50	-5.76	-7.02
	2040 avg.	-5.69	-7.00	-8.30
	2040 dry	-4.60	-5.90	-7.21

Notes:

See last page of the table.

Table 4.7--Surpluses and deficits resulting from alternative demand futures, by water resource regions (continued)

Water resource region	Rainfall Condition	Surpluses or deficits: Projected -20 percent	Projected Demand[1]	Projected +20 percent
		---------billion gallons per day---------		
Great Basin	1985 avg.	1.91	1.21	0.51
	2000 avg.	1.26	0.40	-0.46
	2000 dry	0.88	0.02	-0.84
	2010 avg.	1.07	0.16	-0.75
	2010 dry	0.70	-0.21	-1.12
	2020 avg.	0.89	-0.06	-1.01
	2020 dry	0.52	-0.44	-1.39
	2030 avg.	0.75	-0.24	-1.23
	2030 dry	0.38	-0.61	-1.60
	2040 avg.	0.63	-0.39	-1.41
	2040 dry	0.25	-0.77	-1.79
Pacific Northwest	1985 avg.	67.94	65.82	63.71
	2000 avg.	66.22	63.68	61.13
	2000 dry	60.14	57.59	55.05
	2010 avg.	65.71	63.04	60.36
	2010 dry	59.63	56.95	54.28
	2020 avg.	65.22	62.42	59.63
	2020 dry	59.14	56.34	53.55
	2030 avg.	64.83	61.93	59.04
	2030 dry	58.74	55.85	52.96
	2040 avg.	62.58	59.13	55.68
	2040 dry	56.50	53.05	49.59
California	1985 avg.	41.17	36.74	32.31
	2000 avg.	36.98	31.55	26.12
	2000 dry	-0.65	-6.09	-11.52
	2010 avg.	35.73	30.02	24.31
	2010 dry	-1.91	-7.62	-13.33
	2020 avg.	34.55	28.57	22.59
	2020 dry	-3.09	-9.07	-15.05
	2030 avg.	33.60	27.41	21.22
	2030 dry	-4.04	-10.23	-16.42
	2040 avg.	32.74	26.37	19.99
	2040 dry	-4.90	-11.27	-17.65

Notes:

See last page of the table.

Table 4.7--Surpluses and deficits resulting from alternative demand futures, by water resource regions (continued)

Water resource region	Rainfall Condition	Surpluses or deficits Projected -20 percent	 Projected Demand[1]	 Projected +20 percent
		---------billion gallons per day---------		
Total contiguous U.S.	1985 avg.	270.24	251.69	233.15
	2000 avg.	251.25	228.24	205.22
	2000 dry	128.20	105.19	82.17
	2010 avg.	244.47	219.95	195.42
	2010 dry	121.43	96.90	72.38
	2020 avg.	238.31	212.40	186.50
	2020 dry	115.26	89.36	63.45
	2030 avg.	228.56	201.42	174.29
	2030 dry	109.49	82.35	55.22
	2040 avg.	225.11	196.31	167.50
	2040 dry	102.06	73.26	44.45

Notes:

1. The surplus or deficit for projected demand comes from Table 4.1. The projected demand is presented in Table 4.1 as the offstream consumptive use for agricultural and non-agricultural uses. To compute the surpluses and deficits in this table, the offstream consumptive uses in Table 4.1 were decreased and increase by 20 percent, respectively.

remain are between 10 and 15 percent of the optimal levels for habitat and recreation; low enough that many users may not notice the difference.

The demand drop does not make major headway in reducing the projected deficits in the Lower Colorado region. The deficits still hover around 80 percent of the baseline deficits (a couple of percent less in dry years, a couple of percent more in average ones).

In the Great Basin region, a 20 percent drop in projected demand would eliminate all deficits. A small surplus of 25 mgd would occur even in the dry year at 2040.

In California, a 20 percent drop in demand would result in the largest absolute reduction in consumption--6.4 bgd--of any region. A drop of this magnitude would reduce the deficits in dry years to between 3 and 5 bgd--15 to 30 percent of average streamflow. These percentages are still large enough to be problems in a dry year, but small enough to be manageable with reservoir storage saved from wetter years.

Summary

Demand reductions are the more likely scenario given 19-million-acre reduction projected in Department of Agriculture (1987). On a national basis, the projected drop in irrigated acreage amounts to a 30 percent reduction. Because consumptive use for irrigation amounts to 75 percent of total consumptive use, a 30 percent drop in acreage equates roughly to a 25 percent drop in total water consumption. For the 30 percent drop in irrigated acreage to occur, the assumptions of the RCA Appraisal will need to be fulfilled--chief among them the gains in crop yields from genetic improvement, gains from adoption of new technologies, and drastic changes in crop price support programs. The interested reader should see the RCA Appraisal for a detailed discussion of the assumptions underlying the decline in irrigated acreage.

A reduction in demand of 20 percent will alleviate the deficits in the Lower and Upper Colorado, Rio Grande and California regions, and eliminate them in the Great Basin. Significant problems will still exist in the Lower Colorado basin and in California towards the end of the projection period even if demand drops 20 percent. Additional measures will be needed to assure reliable, long-term supplies for those areas.

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Notes

Chapter 5

ECONOMIC, ENVIRONMENTAL AND SOCIAL IMPLICATIONS OF THE PROJECTED SUPPLY AND DEMAND SITUATION

The economic, environmental and social implications of continuing water use at projected levels are discussed in this chapter. The implications arise from two sources. First, some implications arise as direct result of projected shortages in supply. In this case, the implications help describe the consequences of the projections. Some readers may have difficulty envisioning how the numerical statements of shortages will affect them. The narrative discussion of implications can make the impact of the supply-demand situation more understandable and more personal. Second, some implications arise as a direct result of demographic changes, even where supply shortages are not likely to occur before 2040. For example, population increases will cause increased growth in urban areas. Increased urban development has implications for water resources even though sufficient water supplies may exist.

Implications of Water Shortages

The Rio Grande, Upper and Lower Colorado, Great Basin, and California water resource regions are projected to have water shortages of varying degrees by 2040. The water balances presented in Chapter 4 demonstrate that there are three alternative ways to balance water demands and water supplies and avoid shortages: (1) reduce off-stream demands; (2) increase the level of groundwater pumping; or (3) reduce in-stream flows and accept degradation of fish and wildlife habitat. In each of these regions, irrigation is the off-stream water use responsible for more than two-thirds of water consumption. Irrigation is also the lowest valued offstream use in each region. Consequently, in reducing off-stream demands, the implications fall most heavily upon the agricultural sector of the economy and society.

Economic Implications

Irrigated acreage in the basins projected to experience water shortages amounts to about 5 percent of the total cropland acreage in the U.S. and about 14 percent of the total crop value. California contributes two-thirds of this value percentage from two-fifths of the acreage. The majority of the acreage irrigated in the other water-short regions produces relatively low-valued crops (Day and Horner 1987).

<u>Economic Implications for California</u>--California produces more fruits, nuts, and vegetables--specialty crops--than other regions. For example, over 200 different crops are grown commercially in the San Joaquin Valley, with at least

125 of those contributing significantly to the food supply and economy of the area, state and nation. Five San Joaquin Valley counties which are heavily irrigated are among the nation's 10 highest producers of agricultural commodities, gross value basis (San Joaquin Valley Drainage Program 1987). Water shortages in California, infrequent though they may be, will cause significant price shifts for certain crops in certain seasons (e.g. winter lettuce and table grapes) where California irrigators dominate produce markets. Shortages will also cause significant changes in the quality of produce available. The combination of price and quality changes may cause consumers to alter consumption patterns, foregoing certain products or purchasing substitutes. If consumers shift purchases, the ripple will be felt throughout the agriculture and food processing industries of California, including fruit and vegetable processing, produce transportation, wholesaling and retailing, poultry and dairy processing, grain milling, cotton ginning, and processing of animal feeds. Thus, any changes in agricultural production will be greatly magnified in the California region.

<u>Economic Implications for the Southern Rocky Mountains</u>--Water shortages in the Upper and Lower Colorado, Rio Grande and Great Basin regions affect crops of lesser value than the ones in California. The commodities produced under irrigation in these regions include wheat, corn, alfalfa, cotton, and rice. From a national perspective, the irrigated outputs from these four basins are a relatively minor contribution to total supply. Consequently, water shortages in these regions will cause mostly local impacts. Producers in other parts of the U.S. where water is not in short supply will be able to expand production to fulfill national market demands.

Hanchar and others (1987) analyzed changes in irrigated acres and crop production resulting from shifts in exogenous crop production variables between the 1976-1980 period and 1981-1985 period. From the earlier to the later period, crop production costs increased as a function of increased energy costs. Average irrigated acreage declined in heavily-irrigated Arizona, Texas, and Oklahoma, causing irrigation to cease on some acres. The shifts that occurred between the two periods preview the shifts likely to occur when water shortages emerge in the Lower Colorado and Rio Grande basins. The key factor in the study was the increase in energy costs. In addition to driving up the cost of pumping groundwater, energy cost increases made other factors of production, such as fertilizer and pesticides, more expensive. Irrigators use more of these factor inputs than dryland farmers.

Hanchar and others (1987) reported that in Texas, Oklahoma, and Arizona, the area irrigated decreased by 1.9 million acres. In addition, the cropping patterns did not change significantly. Grain crops, pasturage, and silage--livestock feedstuffs--absorbed the bulk of the cuts. The implication of taking the bulk of the production cut in livestock feedstuffs is that the regional livestock industry will bear the brunt of the impact of the cutback in irrigated acreage. In New Mexico, on the other hand, the area irrigated increased 78,000 acres (9 percent). More important, the cropping pattern changed significantly. Grain crops, pasturage, and silage showed minimal change. But cotton acreage rose 7 percent, oil crops acreage rose 100 percent, and fruit, nut and vegetable acreage rose 530 percent. The obvious shift was to higher-valued crops. California showed a similar shift to irrigating

higher-valued crops--pasture and silage acreage dropped about 20 percent but cotton acreage rose 30 percent and fruits, nuts and vegetables rose 17 percent. To the extent that farmers can shift production to higher-valued crops as irrigation becomes more expensive (due to higher water costs/shortages), they can cushion economic impact of the decline in acreage irrigated. However, the potential of the economy to absorb additional supplies of higher-valued products is not unlimited. To the extent that export markets for these commodities can be developed, farmers can expand beyond the limits imposed by demographic changes in the U.S. population.

The Department of Agriculture (1987) has projected that irrigated acreage will decline by 19 million acres by 2030. The Appraisal outlined several factors expected to contribute to the decline, including advances in technology, increases in crop yields from genetic improvements, higher costs of production in water-short areas, and elimination of price support systems. In the areas where water shortages are projected for this Assessment, significant economic impacts on suppliers of farming inputs are expected as the acreage irrigated declines. Several statistics from the Appraisal about irrigated farms illustrate the potential impact for farm suppliers. Compared to the average dryland farm, the average irrigated farm has 2.5 times as much money invested in land and buildings; twice the value of machinery and equipment; 4 times the value of crops; 2.3 times the value of livestock sales; twice the fertilizer requirements and triple the pesticide requirements; and they use more than three times the energy; 5 times the labor; and 7 times the specialized contract labor. Each acre of irrigated land converted to dryland farming will cause impacts on bankers, equipment dealers, farm supply businesses, agricultural chemical suppliers, fuel and electricity suppliers, farm laborers and contractors.

Environmental Implications

Reducing off-stream demands by reducing irrigation in the areas projected to experience water shortages will create additional environmental problems, chiefly dealing with salinization. The alternatives of increasing groundwater mining or tolerating a reduction in fish and wildlife habitat and recreational use of surface water sources also have environmental consequences.

Salinization--Salinization is a problem in arid and semi-arid areas where precipitation is insufficient to leach salts from the soils. If the soil moisture around plant roots contains too much salt, most crops cannot absorb the water and nutrients needed to germinate and grow well. Saline (excessive salts, mainly chloride and nitrate) and sodic (excessive sodium) conditions are lowering productivity on 10 percent of the nation's crop and pasture land, including nearly one-fourth of the irrigated crop and pasture land. Six of the western water resource regions have salinity and/or sodicity problems on one-third or more of crop and pasture land, according to the Appraisal. Notable areas where salinity is increasing are southern California; the lower Gila River basin, Arizona (major tributary to the lower Colorado River); and parts of the Rio Grande basin in southern New Mexico and west Texas. These are all areas where water deficits were projected to increase in Chapter 4.

Saline conditions in soil are remedied by applying a sufficiently large amount of water to the soil to leach the salts out of the plant root zone. The salts are either carried down to aquifers and then to streams or run off overland directly to streams. The point is that the salts are not neutralized or bound in any sense, merely moved off-site, typically in dissolved form. As water shortages emerge as a significant problem in areas where salinization is also a problem, less water will be available for leaching. Less water will also be available in streams to dilute and carry the dissolved salts away. Farmers further downstream will also wind up with saltier water for their irrigation supply. So as water shortages emerge, salinity will also increase in importance in the five water resource regions.

Salinity occurs naturally in many of the western regions. About half of the salinity in the Colorado River at Hoover Dam is attributed to natural sources, the remainder comes from water use. Of the salinity attributable to water use, three-fourths comes from irrigation (Colorado River Water Quality Office 1986). In its headwaters on national forests in north-central Colorado, the salinity concentration of tributaries to the Colorado River is only about 50 parts per million. At Imperial Dam, near the border with Mexico, salinity concentrations have fluctuated between 608 parts per million (in 1986 after record high flows flushed and filled the major reservoirs on the Colorado River) and 826 parts per million (in 1982). Without applying control measures, salinity is projected to increase following the historical rising trend to more than 1000 parts per million at Imperial Dam by about 2010 (Colorado River Water Quality Office 1986). The Environmental Protection Agency's public drinking water standards limit total dissolved solids--of which salinity is a component--to less than 500 parts per million. Consequently, water in the lower reaches of the Colorado River must be treated by expensive desalinization processes to render it potable. The need for and cost of doing so will increase as salinity concentrations increase.

Agricultural losses, either in the form of lower yields or higher production and management costs, begin when salinity concentrations in the irrigation water applied reach 700 to 850 parts per million, depending upon the soil type and crop. Excessively saline water has caused scours, staggers, and occasional blindness in livestock. Excessive salinity in water also renders it unfit fish habitat and damages riparian vegetation contributing to wildlife habitat.

Salinity not only causes on-site effects, but off-site effects as well. Irrigation water return flows carry salinity off-site. The Colorado River Water Quality Office (1986) estimated that off-site damages in the Colorado River Basin alone total $580,000 for every 1-part-per-million increase in salinity concentration at Imperial Dam. About 5 percent of that damage estimate is a direct cost to agriculture, about 25 percent is damage to the regional agricultural economy, and the remaining 70 percent is damage incurred by municipal and industrial users.

A coordinated program for salinity control in the Colorado River Basin has been developed by federal agencies of the Departments of Interior and Agriculture and the Environmental Protection Agency and agencies of the states comprising the basin. The program jointly developed treats salinity as a nonpoint source of pollution. Control measures are designed to prevent 1.3 million tons of

salt annually from entering and mixing with the river's flow. Similar approaches to those being applied in the Colorado River basin can be applied to the other basins when the interaction of saline soils and water shortages creates problems.

In the San Joaquin Valley of California, related problems with irrigation return flows have emerged. Specific salts, such as selenium, have been concentrated in irrigation drainage water and have caused significant health impacts to waterfowl. The fact that selenium can bioaccumulate in the food chain, as demonstrated by waterfowl impacts, coupled with the fact that low levels of selenium are essential for humans yet slightly higher levels can be toxic, have elevated concerns about the safety of food grown in the San Joaquin Valley. Recent research findings have shown that not enough selenium is being added to the parts of crops destined for human consumption to cause changes in diet (University of California, Davis 1988). However, levels of selenium in some farmland areas in the western San Joaquin Valley are high enough to justify careful monitoring. Further, efforts to solve the saline irrigation return flow problems for the valley, and particularly at Kesterson Reservoir, will be costly because of the biologically concentrated levels of selenium that exist there. The high value of agricultural commodities produced in the valley means that considerable expense can be incurred to deal with the problem (San Joaquin Valley Drainage Program 1987). A total of $38.5 million was spent in fiscal years 1986 and 1987 on the program (combined state and federal expenditures).

<u>Groundwater mining</u>--Mining of groundwater occurs when the current rate of water use exceeds the current rate of aquifer recharge. As with other stock resources, such as metallic ores, mining is socially acceptable so long as the rate of extraction is economically efficient and does not cause adverse environmental consequences.

Groundwater levels are currently declining from 6 inches to 5 feet annually beneath 14 million acres of irrigated land in 11 western states where groundwater is the principal source of irrigation supplies. Pumping costs are rising, well yields are declining, and pumping efficiencies are decreasing. In these areas, municipalities and rural residents rely upon groundwater for domestic and livestock supplies. As groundwater levels have dropped, competition among water uses has emerged.

Sloggett and Dickason (1986) describe the agricultural sectors most affected by recent groundwater level declines. Rice producers in Arkansas and Texas, citrus producers in Florida, and grape producers in California are the most severely impacted by recent declines. Since the mid-1970s, more than 2 million acres in the Texas High Plains have converted to dryland farming of different crops because of the increased costs of irrigation associated with pumping groundwater from greater depths. The shifts in crop production, such as converting irrigated cotton, corn, or alfalfa fields to dryland grain sorghum or wheat production, have affected growers of the same crops in other regions of the U.S. As prices rise or fall in national markets responding to decreases or increases in regional and national commodity supplies, some farmers will be gainers and others losers.

New irrigation technologies are often touted as the way to extend the life of aquifers. The new technologies improve water delivery efficiencies. For example, newer equipment operates at lower pressures so less water is lost to evaporation between the irrigation nozzle and the ground. However, adoption of the new technologies has not always caused the desired end of reducing water consumption. Often, farmers continue to use the same volume of water, but irrigate more acres (Sloggett and Dickason 1986). Supalla and others (1982) studying the situation in the Ogallala aquifer area found that increased water efficiency nearly eliminated the increased cost of pumping, so the immediate effect was no change in irrigated acreage.

States and local governments have exerted regulatory control over the groundwater mining issue in some areas. Recent passage of laws and ordinances have now restricted further irrigation development in about 45 percent of the irrigated area affected by groundwater mining. Sloggett and Dickason (1986) and Supalla and others (1982) both concluded that there is no region-wide problem of groundwater mining, at least out to 2020. Any problems that will occur before then will be localized.

Social implications of groundwater mining are related mainly to prospective ways of augmenting supplies or the effects of limiting demands. Increasing supplies using interbasin transfers have been shown both politically infeasible and uneconomical in the Great Plains, so managing the groundwater that is available is the only option. Interbasin transfers have been more acceptable in the Colorado River basin--both Denver and southern California use them.

Concerning ways of reducing demand, Supalla and others (1982) found that farmers prefer demand management to focus on education and information about new research findings. The farmers' preference is to let the cost of pumping water and crop prices manage demand. Other water users prefer demand management that focusses on mandatory restrictions in irrigation water use. Supalla and others found that mandatory restrictions would cause a 3 percent reduction in projected economic <u>growth</u> (average annual growth of 3.65 percent without mandatory restrictions would fall to 3.59 percent annual growth with restrictions). Supalla and others (1982) reported that reductions in economic growth of this magnitude were not acceptable to agricultural interests. These differing points of view illustrate some of the social implications of groundwater mining.

<u>Degradation of Fish and Wildlife Habitat</u>--The discussions on acid deposition and erosion in Chapter 1 outlined the effects of these externalities on wildlife and fish habitat. Excessively acid surface water affects biota low in the food chain and interferes with reproduction and development of fish and wildlife. Erosion results in sediments in streams, which also interferes with reproduction and respiration.

The water supply shortages discussed in Chapter 4 will have adverse effects on instream flows and the habitat for fish, wildlife, and recreation dependent upon adequate flows, already mentioned. The salinity discussion in this chapter also mentioned fish and wildlife effects of saline drainage, especially in the San Joaquin Valley.

Flather and Hoekstra (1988) discuss the effects of low flows and poor water quality on fish and wildlife in additional detail in their report on wildlife and fish, a companion to this report.

Social Implications[1]

__Population__--Population distribution will be strongly affected by water shortages. While it remains for the 1990 Census to reveal whether or not rural areas are continuing to grow faster than urban ones--a trend first reported in 1980--growth will be limited in those areas lacking either sufficient water supplies or delivery structures. Minimum lot sizes of 10 to 35 acres are already being used in some western areas to limit development of groundwater for rural livestock and domestic supplies. The Southeast is likely to experience growth rates even higher than current levels as people and industries choose to move where water is plentiful. Additionally, those northeastern and midwestern areas no longer experiencing as great an out flow of residents as in the 1970s and 1980s will need to address the provision of social and environmental services demanded by a population growing faster than in recent years.

Water treatment to assure reliable supplies and wastewater treatment to avoid environmental degradation are two of the key services that will be affected by shifting population growth trends. Much of the infrastructure for water treatment and delivery in the northeastern and midwestern states is old. The combination of repair, replacement, and expansion will tax the capabilities of many municipalities. Many small towns did not participate in the EPA wastewater treatment construction grant program established by the Clean Water Act because their discharges were below the minimum levels necessary to qualify. However, the towns were not relieved of the burden of meeting the discharge regulations. So in the future, they will be faced with upgrading facilities and adding additional capacity using loans instead of grants. If more growth occurs, the limits of the towns' financial resources will be stretched to the point where major rate increases are the only way to garner the necessary construction funding.

The population composition in the West will also change with the onset of water shortages. As fewer people move into an area, the resident population will stabilize according to prevailing characteristics. If, however, wealthier, more mobile, younger people move to areas with more secure water supplies and accompanying economic opportunities, the communities they leave will experience an increase in the proportion of poor and elderly--groups with fewer relocation options. As the population left in the areas ages, the public services demanded will also shift. The precedents for the kinds of shifts likely to occur are found in cities that relied heavily on iron and steel production from the 1930s to 1950s. The shifts in population composition that occurred as a result of the changes in the steel industry are the same kinds of shifts likely to occur as a result of the projected changes in the agricultural sector in the West.

__Attitudes, Beliefs, and Values__--These social indicators reflect the hardships posed by water shortages. As more time and money are expended securing water, an overall decline in quality of life can be anticipated. Concurrent declines

in the American "can do" attitude, as well as individuals' perceptions that they have a degree of control over their future, can also be expected. Ties to the land--a major factor in rural agrarian lifestyles--will also be weakened as irrigation rights to water, the lifeblood of western family farms, are sold to municipal and business interests able to afford the increased price of water.

Competition among interest groups will increase, encouraging polarization among community members. Examples of affected groups are recreationists (anglers, boaters, hunters), ranchers, real estate and landscaping concerns, as well as high-tech industries dependent on a certain degree of water quality. How to satisfy their competing demands for water use is the water managers' challenge. In many cases, western state and local governments are seeking to diversify local economies by attracting industries that either produce no air or water pollution or that depend upon clean water for production processes. New industrial developments, lured by tax breaks and relocation assistance, bring new jobs to an area and jobs attract people. Often, the new jobs are filled by people from other areas; people with different attitudes, beliefs, and values about resource use that are different from those of long-time residents. The clashes that typically emerge over future resource uses in such settings are often "strawmen" for differences in attitudes, beliefs, and values among newer versus older residents. The ballot box and the electorial process become the means of settling many of these disputes.

Any social analysis of prospective changes in water use and management should incorporate three basic kinds of information. First, the analyses should recognize that attitudes, beliefs and values vary by population cohort and background. Second, the analyses should use marketing survey techniques and other sociological instruments to elicit the attitudes, beliefs, and values, about proposed changes in water use and management by cohort. Third, political polling techniques should be used to evaluate the likelihood that specific cohorts will vote in certain types of elections or take some other action, such seeking injunctions or pursuing litigation. In this way, information on the social implications of resource use changes can be gathered and used by decisionmakers when evaluating alternative management strategies. Too often, such analyses are done only after decisions are made; wise stewardship of natural resources suggests they should be done beforehand.

<u>Social Organization</u>--Institutions in communities experiencing water shortages will be affected in a variety of ways. As population decreases and competition for water increases, local governments will be required to increase their level of technical and political knowledge of water supply issues and negotiation/consensus-building and regulation/enforcement/litigation skills. Gaining knowledge about sophisticated water-related technology and conservation programs and developing the ability explain the necessity for and consequences of the technology and programs to different audiences with a variety of technical backgrounds will also become crucial. Internal conflict between agencies committed to water quality and those fostering economic growth with increase. Tools of government, such as enforcement of regulations and ordinances, eminent domain and annexation, will assume greater importance. Officials, such as county extension agents, are liable to assume positions of leadership in implementing technical and complex changes in resource use.

Local governments will be required to address other challenges caused by water shortages. The growth in the proportion of elderly and poor cited earlier will increase demand for social services such as health care and income assistance. Conversely, the amount of tax revenue available to communities to pay for such services will decrease as the younger, more affluent sector moves away. Property tax revenues will go down as farm property values decline due to reduced productivity in dryland agriculture compared to irrigated agriculture. The lack of sufficient water to attract additional jobs may also lead to reductions in residential property values. Sales tax revenues will reflect a reduction in the number of homeowners who would ordinarily be making major purchases, such as of new carpeting and appliances, associated with moving into an area. Income tax revenues will decrease due to the lower number and smaller size of taxable incomes.

Land Use Patterns--As water becomes less available and more expensive, agricultural operations dependent upon irrigation will change either to dryland farming or crop production will cease and native vegetation will begin to reoccupy the site. In many of the areas where water shortages are projected, native vegetation is range grasses or shrubs.

The major reason why agricultural land goes out of production is that the landowner can obtain a higher economic return by putting his land to some other use--including leaving it idle.[2] In the 1800s, before the advent of inorganic fertilizers and farming practices that conserved soil, land was farmed until the natural fertility of the soil was exhausted and then it was abandoned. For example, cropland abandonment in the South from the 1880s to the 1950s and its subsequent reversion to native vegetation--southern pine forests--was one of the principal factors behind the rapid expansion in the southern forest products industry since World War II. When cropland moves out of agricultural production in the future, most of it will likely not return to crop production. The Appraisal projects 160 million acres of cropland will be idled by 2030.

Cropland will also go out of production for reasons other than inadequate returns to farming. Some will shift to urban and suburban uses. Of the agricultural land going to urban and suburban uses, 63 percent will come from cropland, 18 percent from pasture, 13 percent from forest, and 6 percent from other agricultural land, such as orchards. The Appraisal notes that 80 percent of the cropland likely to move to non-agricultural use by 2030 is prime farmland. The reason prime land is most likely to go to urban uses is that settlements often began in the center of some of the most fertile areas to provide goods and services to farmers. As these settlements expand, the expansion eats into the prime cropland base.

Much prime agricultural land is river bottom land. Many of the agricultural settlements began along streams because the waterways provided a means of transportation and waterpower provided a means of processing crops. So as river bottom land moves out of agriculture to urban uses, water-related impacts result. Periodic flooding of river bottom cropland is what enhanced the fertility of the land, making it prime agricultural land in the first place. The major implication of expanding urban development on flood plains is that these areas will periodically be flooded, causing economic damages. The land use implication is that additional flood protection measures will be needed.

Structural flood protection measures alter natural stream channels and ecosystems, creating environmental implications. Non-structural flood protection measures, which are now in vogue, often have adverse social consequences. Landowners may perceive the zoning and other non-structural measures as infringing upon their rights and diminishing the development value of the land. There is no way to avoid implications of one sort or another when expanding development, and particularly on flood plains.

The use of zoning as a means of regulating growth will become more prevalent. This increase in zoning is liable to prove particularly contentious. To a large extent, the West was settled by people who strongly valued personal freedom. The concepts of homesteading and building wealth from scratch through land resource utilization--appropriating public domain land for use in ranching, farming, mining, logging--created the still-prevalent attitude that government exists mainly to guarantee personal rights. The use of government zoning powers to avoid "the tragedy of the commons" is only now emerging in the West. This development, while common in New England as early as the 1700s, runs counter to the heritage and established social organizations of many small western communities. As resource use conflicts grow, social organizations in the West are likely to evolve in a manner similar to their eastern predecessors. Over time, one would expect the West to become more "liberal" in the sense of the populace agreeing to subordinate personal goals for promotion of the common good.

Another land use impact of water shortages is that water-related recreation will be curtailed due to lack of water. Water access and use points--beaches, riparian camping areas, boat launching areas--will become more lightly used. Use during dry seasons may cease altogether. Second, concern over conserving remaining water may result in restricting access to key watersheds to avoid damage. Damage may be to the land, such as by wildfire, or to the water, such as by reducing the chances of giardia infestations.

The importance of public forests and rangelands and the importance of wetlands on all ownerships will become more apparent as water shortages emerge. Chapter 3 outlined the current trend in wetlands area. Unless this trend is reversed, waterfowl populations will become increasingly endangered. Recreation related to wetlands, particularly fishing for finfish and shellfish and waterfowl hunting, will diminish in quantity and in quality--social impacts of considerable importance to anglers and hunters. Support for the continued existence and possible expansion of wetlands will increase.

<u>Summary</u>--Without modification of current rates of growth in water demand, large areas of the West will face water shortages early in the 21st century. These areas need to implement technological and behavioral changes without delay if they are to ensure a continuous water supply without degradation of fish and wildlife habitat or excessive groundwater mining.

Summary

In this Chapter, the environmental, social, and economic implications of the current and projected future supply-demand situations for the water resource

and water users have been reviewed. The projections developed and compared in Chapters 2, 3, and 4 are based on recent trends in water use and management from 1960 to 1985. The goal was to describe what the water use situation will be in 2040, and its concomitant environmental, social, and economic implications if society does not change its recent patterns of water and related land resource use. The major implications are:

— Water shortages will become prevalent in the California, Upper and Lower Colorado, Great Basin, and Rio Grande water resource regions.

— Water shortages will increase the cost of food for humans and livestock. Substantial price increases can be expected, particularly in dry years, for products such as vegetables, fruit, and nuts. To the extent that production of livestock feed and livestock production cannot be shifted to other regions of the U.S., the prices of red meat, primarily beef and mutton, and related livestock products, such as wool, will increase. The price of cotton products will also increase if cotton production cannot be shifted from the Southwest to other parts of the U.S.

— Water shortages will disrupt local economies, especially those relying heavily upon irrigated agriculture and the processing, sale, and transportation of crops and products grown under irrigation.

— Water shortages will cause major social impacts on local residents and their communities.

— A continuation of recent trends will lead to groundwater mining.

— A continuation of recent trends will reduce wildlife and fish habitat and other instream uses, such as recreation.

— Continuation of recent trends in water use will lead to increased salinity, causing additional disruptions in local economies relying upon surface water sources for potable supplies and to farmers depending on the water for irrigation.

— Continuation of recent trends in wetlands conversion will lead to significant additional reductions in waterfowl populations and reduction in fishing, hunting, and other recreational benefits.

— Expansion of urban areas will increase at the expense of prime agricultural land.

These projections and their implications are only "most likely" in the sense that if society makes no changes in water use patterns, then the projections are most likely to be attained. Many of the implications of continuing recent water use trends describe a painful transition in lifestyles to 2040, especially in the southern Rocky Mountains and California.

The good news of this Assessment is that we have an opportunity to change the way water has been used in recent years and avoid many of the adverse implications described in this Chapter. We have made many changes in how we

use water since the 1972 passage of the Clean Water Act. That was strong medicine for our water quality problems, but we needed it. More changes in water use are called for; many will call for taking some pretty strong medicine now to avoid major problems in the future. Whether the nation chooses the distasteful medication now or chooses to tolerate the pain of the disease in the future is uncertain. The painful future consequences of the nation's addiction to cheap water and waste disposal have been described in this Chapter; the medication and its consequences are described in the next two.

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Notes

1. This section was prepared by Susan Johnson, Sociologist, who is a member of the RPA Staff.

2. Some current agricultural programs pay farmers for idling land previously used for growing certain crops.

Chapter 6

OPPORTUNITIES TO IMPROVE THE MANAGEMENT OF WATER AND RELATED FOREST AND RANGELAND RESOURCES

The objective of this chapter is to highlight the most significant opportunities available for improving the management of water and related land resources. The implications of water shortages discussed in Chapter 5 provide many opportunities for altering annual crop production practices to avoid adverse environmental, social, and economic impacts. Opportunities whose primary application is to crop and pasture land have not been addressed here. In this chapter, the focus is narrowed to matters of interest to forest and range managers.

The opportunities presented are all high-priority; the order of presentation here does not reflect a priority ranking. The opportunities were selected without regard to who should implement them. Some are opportunities for both private groups and public agencies. Some of the opportunities requiring government involvement are opportunities for federal agencies as well as state or local agencies. The common thread is that the opportunities all pertain to forests and range management.

The opportunities to be discussed are:

Ensuring suitable flows for in-stream water uses, emphasizing fish and wildlife habitat and recreation;

Improving watershed condition, including special emphases on:
- Maintaining water quality;
- Managing the timing of runoff;
- Improving riparian areas; and
- Enhancing soil productivity.

Encouraging use of non-structural watershed improvement measures to avoid flood damages.

Implementing non-point source pollution abatement approaches for silvicultural and range management activities; and

Reversing the trend of losing wetlands.

Ensuring Suitable Flows

The water budget analyses of Chapters 3 and 4 reveal that when deficits occur in the Lower and Upper Colorado, California, Great Basin and Rio Grande water resource regions, projected low flows will be insufficient to provide good survival habitat for fish and wildlife or recreation. The population dynamics for most fish and wildlife species are such that having poor survival habitat for an extended period an average of one year in five is too frequent a repetition to provide sustained high-quality fishing and wildlife-related experiences. The projections indicate that the situation will worsen in proportion to increases in demands for off-stream surface water use. In the regions where water shortages are projected, many rivers originate on public lands, so public land managers have opportunities to pursue land management practices that augment in-stream flows and through administrative procedures to ensure protection of minimum instream flows. These opportunities can be realized in two ways: manipulate vegetation to augment low flows and protect instream uses through administrative controls and state water rights procedures.

Opportunities to Manipulate Vegetation to Augment Low Flows

Research has demonstrated that timber harvesting patterns and frequencies can be planned so as to increase water yield from some sites. The bulk of the increase comes from the fact that timber harvesting reduces evapotranspiration. A second benefit is that if the cutting patterns are properly planned, the residual stands will trap and concentrate drifting snow in partially cut areas, much as snow fences are used to trap snow and keep it off roadways. The cutting intensity can be designed so that effective trapping occurs yet enough shade is provided to retard melting in early summer. In this way, the period of snowmelt is stretched out and high springtime peak flows are reduced. The main effect of this practice is to spread the snowmelt out over a longer period of time, making more of the meltwater usable.

Troendle (1983) concluded that with prudent management of high-altitude subalpine forests in the Rocky Mountains, a 0.1 to 0.25 acre-foot per acre increase in water yield could be realized. By altering the aerodynamics and energy budget of the forest, timber harvest alters the accumulation and melt characteristics of the snowpack. These impacts are partially translated into flow changes. Second, eliminating the vegetation reduces evapotranspiration losses and this can also be translated into increased flows. Because vegetation recovers after cutting, and as it does its evapotranspiration increases, only one-fourth to one-third of the acreage under this kind of management will be producing increased yield due to reductions in evapotranspiration at any one time. The potential for increasing water yield is greater in the northern than in the southern Rocky Mountains, but areas in the Upper Colorado and Great Basins are amenable to these vegetation management practices.

Douglas (1983) concluded that water yield from well-stocked northeastern forests could be increased from 0.3 to 1.0 acre-feet per acre the first year after clearcutting. But as the forest grows back, the water yield drops logarithmically back to base levels. The duration of the increased yield

averages 1.9 years for each 0.1 acre-foot of increase. There are two problems with applying these research findings. First, the diversity of landownerships and ownership objectives makes capturing the full potential increase nearly impossible because of the difficulty in coordinating cutting patterns. Second, many stands in the northeast are understocked, so they have less potential increase in water yield because they are not currently at maximum evapotranspiration. Douglas concluded that the greatest potential for increasing water yield is on municipal or utility watersheds; but even here, timber sale revenues will often dictate cutting patterns rather than the increased value of the extra water produced. In short, Douglas concluded that we know how to increase water yield in the northeast, but until shortages occur, there is no incentive to implement the research findings.

If sufficient reservoir storage existed to contain all springtime runoff, then it would not matter when snow melted. All meltwater could be captured. It could then be metered out into streams during dry periods to maintain adequate low flows and good survival habitat. But sufficient storage does not exist and sites for building additional reservoirs are scarce and rarely feasible either from environmental or economic efficiency perspectives. So structural solutions to the problems of maintaining adequate low flows do not appear promising.

Opportunities to Ensure Water Needed to Support Instream Uses

In some states where the appropriation doctrine is in use, the water in streams is oversubscribed in drier years--not enough water is available to meet all users' needs. Instream water uses are not recognized as a beneficial use for water appropriation purposes in many states, or where they are recognized, are defined as junior to other uses. In such situations, instream water uses are foregone to satisfy other water uses. Thus, there is little opportunity to ensure instream flow rates providing, at a minimum, good survival habitat and recreation.

There is strong support from anglers, hunters, and recreationists for increasing and enhancing fishing, wildlife, and in-stream recreation experiences. The land manager has an opportunity to use the support of groups advocating maintenance of suitable flows to help influence how instream flows are protected. The partnerships thus established often provide opportunities for addressing other land management issues.

Improving Watershed Condition

The fundamental concepts of watershed condition and its relationship to water quality and quantity were outlined in Chapter 1. The percentage of watersheds in the lowest condition class--needing major capital improvements to regain productivity and produce top-quality water--varies between 13 percent (South) and 25 percent (North). Watersheds in this Investment Emphasis class typically have vegetation and soils that have experienced significant disturbance. Often, the vegetation is sparse or lacking, and much of the soil surface is exposed to direct impact of precipitation. In such situations, the water quality of runoff is rarely up to the level in Table 3.2.

Water supply utilities, whether public or private, have long emphasized maintaining high-quality supplies. In areas where the riparian doctrine of water use is in force and surface waters are the source of supply, utilities have sought to acquire land adjacent to streams and reservoirs and then restrict trespass. The objective has been to minimize the potential for water contamination. Utilities have viewed this approach as less expensive than installing water treatment processes to clean up the water.

In areas where the appropriation doctrine of water use is in force, municipal water utilities have taken their place in the queue of water users to obtain supplies. Over time, and especially west of the Great Plains, utilities have become less confident of having adequate supplies. Further, the increasing amounts of dissolved salts, including nutrients, in surface waters have reduced its potability in many places. Therefore, western utilities are beginning to compete for water; often seeking to purchase more-senior rights from agricultural interests. The utilities' goal is to divert water nearer its source, which means the supply will be of more reliable quantity and higher quality. So it matters not whether the utilities are operating under the riparian or appropriation doctrines, there is an increasing emphasis by utilities on securing and maintaining high-quality surface waters.

An Increased Emphasis on Maintaining Water Quality

The land management consequence of utilities' search for reliable, high-quality surface supplies is that utilities will become much more interested in watershed management activities upstream of where they withdraw water. In coming years, utilities will subject to more critical scrutiny those activities that disturb ecosystems and increase the amounts of salts, sediments, or other pollutants moving into streams. If there is an increasing trend in those activities in watersheds producing potable supplies, then utilities are expected to become vigorous participants in the planning, review, and environmental analysis process of watershed managers. In such circumstances, utilities and other water users dependent upon high-quality water will become effective advocates for mitigating ecological disturbances and for rehabilitating areas where previous disturbances are contributing to in-stream water quality degradation.

An Increased Emphasis on Managing the Timing of Runoff

The vegetation management activities discussed as a way of ensuring suitable flows, above, represent one of the three opportunities for managing the timing of runoff. In addition to using timber harvesting patterns to trap snow, snow fencing can be erected to concentrate blowing snow in drifts and prolong melting into early summer. Snow fencing, on a scale much greater than the woven wooden lathe typically erected along roads in the East, is particularly useful for trapping snow in cirques above timberline and on high-altitude rangeland. Weather modification, primarily cloud seeding, can be used to increase snowfall in watersheds. Used in conjunction with vegetation management and large-scale fencing, opportunities exist to store considerable amounts of snow in drifts that will take longer to melt.

Currently, snow melts in the headwaters of water-short regions in April to early June. Storage reservoirs fill up with meltwater early. Because snowmelt occurs when crop irrigation needs are low, the water that cannot be stored moves downstream underused. In July and August when irrigation and other offstream and instream water needs are high and instream flows have declined, water stored in reservoirs is released to help meet needs. The objective of trapping snow and delaying snowmelt is to extend meltwater runoff into the summer to help meet emerging summertime needs for water. The consequence is that the beginning of reservoir drawdown can be delayed, making more water available in late summer and early fall when instream flows and needs are greatest.

The challenge to watershed managers is to combine these three approaches--vegetation management, snow-trapping structures, and weather modification--to influence the timing of water availability.

An Increased Emphasis on Improving Riparian Areas

Riparian areas, the strip of land and vegetation bordering a stream or lake, are the last line of defense against pollutants reaching streams and lakes. They are also the primary buffer between land management activities and adverse effects upon fish, wildlife, and other organisms that are part of the aquatic ecosystems. Riparian vegetation often shades streams, keeping water temperatures cooler and more amenable to fish and other aquatic organisms. The vegetation also provides cover for wildlife. Recent research has demonstrated the beneficial effects of allowing riparian vegetation debris to modify stream channel configurations and augment the cover and structure normally provided by rocks and boulders in streams. Riparian vegetation also slows down precipitation runoff, thereby reducing peak flows during high flow periods.

The emphasis on maintaining water quality will also manifest itself in an increasing concern over safeguarding riparian areas. The use of mechanized equipment, heavy livestock grazing, or other use that can disturb riparian vegetation will be increasingly viewed as unacceptable resource management. Active programs to assist the recovery of riparian vegetation damaged by trespass or overuse are needed in many watersheds in the Investment Emphasis condition category.

The Opportunity to Enhance Soil Productivity

Soil productivity refers to the ability of a soil to produce vegetation. The concept of soil productivity includes all the chemical, biological, and physical aspects of a soil that affect its ability to sustain production of vegetation over time. Many factors discussed in Chapters 1 to 5 influence soil productivity. For example, erosion results from physical practices (e.g. soil disturbance or vegetation removal) that lead to topsoil moving off-site. The sediments carry nutrients away with them, reducing the site's ability to sustain vegetation production at previous levels. Acid deposition affects soil chemistry by making aluminum ions more mobile and altering nutrient relationships--both of which lead to reductions in plant productivity.

When treating watersheds in the Investment Emphasis class, opportunities exist to affect more than the physical aspects of the site, such as halting erosion. Treatments should be designed that also consider the chemical and biological aspects of soil productivity. Chemical considerations include restoring nutrient balances, such as by fertilization or inclusion of legumes in revegetation plans. Biological considerations include maintaining and enhancing biological diversity by restoring a mixture of native species instead of using only one or two exotic varieties. Site examinations for planning watershed recovery investments need to examine all aspects of soil productivity so the root cause of the problem can be cured instead of only treating symptoms.

The Opportunity for Improving Watershed Condition

The increasing emphasis on maintaining high water quality, reliable stream flows, and diversity in fish and wildlife populations in streams and lakes presents a significant opportunity to build a consensus for improving watershed condition. The improvement tasks needed include rehabilitating watersheds and riparian areas needing major investments, restoring soil productivity, and reducing adverse water quality impacts. The consensus will take the form of increased demand to restore adequate vegetation to watersheds, especially riparian areas, and to hold sediments and nutrients on the site. Adherence to nonpoint-source pollution regulations and use of best management practices will be supported by the water clientele as a way of encouraging the rehabilitation and restoration of problem watersheds. Even though the cities served by the water utilities may be far removed geographically from the watersheds needing work, the strong support of city governments and the utilities for improving watershed conditions will be felt. Forest and rangeland managers should recognize that this consensus is emerging and plan proactive ways of using the opportunity to help achieve rehabilitation and restoration goals.

Where watersheds are in middle-class condition, called "Special Emphasis", integrated resource management is the primary vehicle for facilitating additional watershed rehabilitation or preventing additional degradation of sensitive watersheds. The opportunity afforded by the increased attention to maintaining water quality and altering runoff timing also provides additional support for managing these areas. For example, the use of interdisciplinary teams to develop environmental assessments and prepare management prescriptions for watersheds in the Special Emphasis class will be a primary vehicle for maintaining and improving watershed condition. Included in this is an increased emphasis on seeking coordinated multi-disciplinary approaches to managing riparian areas. Special attention will be needed to address the resource characteristics making the watershed especially sensitive to use.

Watershed researchers can also use these opportunities to create support for developing and testing innovative ways of protecting watersheds and riparian areas from degradation, and for accommodating multiple uses. Involving watershed researchers in resource planning and taking advantage of their findings to mitigate adverse impacts will become increasingly important. The contributions of watershed specialists toward making other resource uses feasible by mitigating detrimental watershed impacts were often overlooked in the past. The increased attention that will be devoted to maintaining water

quality and riparian areas will result in more accurate accountability for successes in watershed rehabilitation, restoration and management.

Nonstructural Flood Damage Reduction

Society has three general ways of responding to flood damages. One is to provide direct economic relief to those suffering losses. The Federal Emergency Management Agency (FEMA) coordinates government responses to flood disasters. Grants and low-interest loans to residents as well as direct recovery measures to restore infrastructure (e.g. roads, bridges, electricity, sanitation) are examples of the services delivered by FEMA. The second way of responding to flood damages is to build structural measures designed to control flood waters. These include dams, dikes, levees, floodwalls, diversion structures, and channel alterations. The third way of responding to flood damages is to use nonstructural measures to reduce flood peaks and to reduce the potential for flood waters to damage investments. Forest and rangeland managers have opportunities to participate in the latter approach through watershed management.

Flood Damages in Rural Areas

The bulk of flood damages--60 to 70 percent--occur in rural areas, largely to agricultural investments. Although urbanization is increasing, rural damages are still projected to account for half the annual damages in the next century. Most of the damage is to crops and improvements on flood plains. The flood plains are some of the most fertile soils. As land use shifts in agriculture occur, these sites will be among the ones where crop production will become even more concentrated. Flood plains are also often used for grazing. Improvements subject to flood damage include fences and structures, such as watering structures and shelters. In mountainous terrain, stream bottoms are common locations for roads and utility lines. These too are susceptible to flood damages, even if properly designed and constructed.

Opportunities to Reduce Flood Damages

Floods occur when precipitation is heavy and the infiltration rate of water into soils is less than the precipitation rate. Thus, much of the rain runs rapidly over the soil surface and into streams. Because forest and rangeland managers have little control over precipitation patterns, frequency, or intensity, the focus of flood damage reduction efforts must be on the two key points of maintaining soil infiltration rates and providing ways to slow down the overland flow of runoff to streams.

<u>Maintaining Soil Infiltration Rates</u>--Generally, the way to maintain soil infiltration rates is to keep vegetation healthy and growing on the site. The principal way precipitation overwhelms infiltration capacity is by the impact of droplets compacting the soil surface. Machine, hoof, or foot traffic across a site can create the same effect. Keeping vegetation growing on a site cushions the effects of traffic and provides the point of initial impact for rain droplets, reducing soil surface compaction. Accumulations of organic debris--forest litter--serve the same purpose.

Opportunities exist to manage land so as to maintain vegetation and litter and protect the soil surface. Wildfire prevention, detection, and suppression are opportunities to conserve vegetation and litter and thereby to reduce flood damages. Rapid watershed rehabilitation and restoration following wildfires, such as by seeding and fertilizing with quick-sprouting grasses, are techniques that have been successfully employed to reduce flood damages after fires. Opportunities will continue to exist to employ such techniques. Additional opportunities exist to develop new and better wildfire recovery techniques, such as hydrophilic mulches that both protect the soil surface and hold water for the vegetation being reestablished and ways of growing seedlings in containers more rapidly than is possible in conventional tree nurseries to speed up the replanting of burned-over sites.

Opportunities also exist to develop new ways of managing watershed vegetation to maintain soil infiltration rates. Many techniques have already been borrowed from agricultural research and soil conservation practices, such as planting trees on the contour instead of straight up and down hills. The opportunity now exists to develop forestry and range applications of more recent agricultural research findings. For example, "conservation tillage" or "no-till" farming is just coming into vogue. These practices no longer use the site preparation techniques common in the 1950s, such as deep moldboard plowing or disking and harrowing. The opportunity exists for forest and rangeland researchers and managers to develop and apply new site preparation techniques and technology to lighten the site impacts and maintain soil infiltration rates.

<u>Slowing Overland Runoff to Reduce Flood Peaks</u>—Inevitably, precipitation events will occur that overwhelm soil infiltration rates. These may be severe events, such as locally heavy thunderstorms that create flash floods, or events of longer duration such that soils get so thoroughly saturated that infiltration and percolation rates bog down. In urban areas, sanitary engineers have been grappling with related stormwater runoff problems for a number of years. Innovations that have become popular in the last decade include altering the design of individual construction projects, such as office parks and shopping centers, to incorporate temporary stormwater detention structures. These structures collect stormwater, but retard its entry into sewers, thereby reducing peak flows to sewage treatment plants. In agriculture, strip-cropping is an example. Strips of forage or field crops are alternated with strips of row crops, both planted on the contour. Runoff from the row crops, such as corn, gets slowed down in flowing through field crops, such as alfalfa. The opportunity now exists to develop ways of applying these stormwater management concepts in forestry and rangeland settings.

There are opportunities to manage riparian areas to slow overland runoff. Not only will the flow of water be slowed, but in doing so, the drop in velocity will allow sediment that moved down slope as sheet or rill erosion to drop out of the water. Many kinds of vegetation can be used to slow overland runoff. Grasses have been favored because of their dense root systems. But other kinds of vegetation can also be employed. For example, when performing site preparation, strips of brush might be left on the contour to slow runoff until forest or range vegetation is reestablished. Other land management

opportunities to reduce or retard runoff include piling logging debris on the contour and making a pass or two with a bedding harrow or a fireplow on the contour to intercept runoff. When laying out roads and trails, they should angle across slopes following contours instead of going straight up or down slopes. Where that is not possible, water bars and culverts will need to be designed into the project to divert and control water. When road or trail locations follow stream bottoms, special care must be taken to avoid damage to riparian areas.

Many flood damages occur when debris is carried downstream with floodwater. Land managers need to take steps to reduce the possibility of debris from forest management reaching streams. Slash is the most likely candidate for reaching streams, especially where valleys are narrow with steep walls and the main haul roads are in the valley bottoms. It is often natural for landings to be located next to roads, so slash often accumulates there also. Managers need to take advantage of the opportunities for slash disposal further up slopes to prevent organic debris from reaching steams. Bridges and livestock fencing and structures are also very susceptible to damage from tree tops and limbs carried by floodwater. Many of the quasi-regulatory programs for controlling nonpoint-source pollution are targeted at reducing debris in streams for this reason.

<u>Summary</u>--Many of these activities are standard practices for mitigating off-site effects of other kinds of resource use. Many of these activities serve more than one purpose, such as reducing nonpoint source pollution. The opportunities to use these practices will continue to grow as the value of agricultural production and suburban development increases in flood plains. They should be practiced by forest and rangeland managers on a routine basis. The challenge is to consistently and reliably apply the practices at every opportunity.

Silvicultural Nonpoint-Source Pollution Abatement Approaches

The smaller areal extent of forest management activities, less intensive site preparation, infrequent harvests, and lower frequency of pesticide and nutrient applications in a given year all result in silviculture generating a much smaller volume of total nonpoint source pollutants than agriculture, nationwide. Although silvicultural activities do not appear to cause problems as pervasive as those caused by agriculture or as severe as those caused by mining, they can still lead to localized water quality problems in places where activities are not well-managed. Where localized problems are occurring, the opportunity exists to use nonpoint-source abatement approaches to clean up the problems. The following states identified silvicultural nonpoint-source pollution as a widespread problem affecting 50 percent or more of the state's waters: Maine, Vermont, North Carolina, Alaska, Idaho, Oregon, and Washington (Myers and others 1985)

Range management activities have been lumped together with pasture management activities in nonpoint source reports (c.f. Myers and others 1985). In spite of that aggregation, range projects involve many of the same kinds of activities applied at periodic intervals. For example, fertilizer and

pesticide applications to range provoke many of the same concerns as fertilizer and pesticide applications to forests. Overharvesting of range forage by livestock can lead to runoff and erosion problems similar to forest problems. Range cover type conversions and reseeding operations often involve burning, alone or in combination with chemical or mechanical treatments, which expose bare soil to erosion. These actions occur on rangelands at frequencies approximating their use on forests. Consequently, range management activities are viewed much more like silvicultural than agricultural activities. Many of the same opportunities for reducing nonpoint-source pollution exist for range management as for silviculture, as do the vehicles for capturing them.

Current Approaches to Implementing Abatement Procedures

Programs to reduce nonpoint pollution from silvicultural activities currently rely upon a voluntary compliance approach in 29 states, a regulatory approach in 5 states (Alaska, California, Idaho, Oregon and Washington) and a quasi-regulatory approach in 6 states (Hawaii, Maine, Massachusetts, New York, New Hampshire, Pennsylvania)(U.S. Environmental Protection Agency 1984). Regulatory approaches control activities directly using forest practices acts. Quasi-regulatory approaches use laws passed for ancillary purposes, such as sediment and erosion control. In western states where forest industry has substantial land holdings and is very active, regulatory or quasi-regulatory approaches are favored. In states with a plethora of small parcels, voluntary, educational, and sometimes incentive-oriented approaches are aimed at private landowners.

Opportunities to Control Silvicultural Nonpoint-Source Pollution

The main nonpoint source pollutants from silvicultural activities are sediment, chemicals from pesticide applications, and organic debris (U.S. Environmental Protection Agency 1984). Principal sources are roads, logging activities, preparation of sites for revegetation, and aerial spraying. Management practices to control these pollutants are well known and well understood. The types of best management practices (BMPs) likely to prove most effective include:

— Better pre-harvest planning;

— Better planning, design, and construction of roads;

— Less soil-disturbing techniques for harvesting, storage, and hauling procedures;

— Closure and revegetation of temporary roads and landings not needed after harvest; and

- Careful application of fertilizers and pesticides.

As in agriculture, adoption of some BMPs will be both within the means and self-interest of the landowner and timber operator. For example, proper planning, design, and construction of logging roads intended for long-term use will lower operation and maintenance costs. In other cases, however, adoption

of BMPs will not be in the economic self-interest of operators. Needs for specialized equipment may put some BMPs beyond the means of the small landowner or operator. Finally, certain BMPs may be unattractive because they result in reduced income. For example, leaving unharvested timber in riparian zones costs the landowner money in the short-run, but the benefits accrue to society.

Nonpoint source problems are fundamentally land management problems. Thus, adopting BMPs that can also save money presents an opportunity to land managers. Opportunities also exist to develop demonstration areas and to show private landowners and land managers how to secure these financial benefits. Demonstration areas also present opportunities for disseminating information and educating landowners about related issues, such as the importance of water quality, the benefits of preserving fish and wildlife habitat, and how to safely conduct harvesting and regeneration operations. Some landowners may need technical or financial assistance to implement abatement procedures during regeneration or intermediate stand treatments. Where abatement procedures do cost the landowner money, the opportunity exists for the federal government to share the cost through programs such as the Forestry Incentives Program. The landowner also has an opportunity to claim the cost of abatement procedures associated with regeneration as eligible costs under the Reforestation Income Tax Credit. The U.S. Environmental Protection Agency (1984) concluded that agencies with programs that reach the land manager or that affect the relationship between the state and the land manager are key to the implementation of nonpoint source controls for agriculture, silviculture, construction and mining.

Reversing the Trend in Loss of Wetlands

Eighty percent of the wetlands lost between the mid-1950s and mid-1970s were attributed to agricultural conversions. Wetlands are lost to agriculture through two primary means: direct conversions by draining and/or clearing; and indirect conversions associated with normal agricultural activities. Although direct conversions are responsible for the majority of the acreage, indirect conversions may be a major factor in some regions (Office of Technology Assessment 1984). Examples of direct conversion include drainage to expand crop acreage in the prairie-pothole region and clearing and draining bottomland hardwood forests for soybean or rice production. Examples of indirect conversions include the general lowering of the water table resulting from irrigation in the region or changing water management practices so that irrigation discharges are no longer available to maintain wetlands.

A number of reasons have been advanced to explain the continued rate of conversion of wetlands (Office of Technology Assessment 1984):

— Elimination of the nuisance and costs of avoiding wetlands within cropland;

— The opportunity to gain relatively productive cropland for the cost of drainage;

-- Changes in farming from a diversified crop-livestock combination to increasing emphasis on row-crop and small-grain production;

-- Rapid increase in tractor horsepower, which increases avoidance costs and facilitates drainage of potholes by providing the power to operate drainage equipment. This allows the landowner to drain his own land during slack periods at low cost.

-- Continued increase in the use of center pivot irrigation systems that are incompatible with wetlands;

-- Short-term farm income variability, which provides investment capital for drainage during periods of high income and increases incentives to expand cropland area;

-- Absence of private returns from maintaining wetlands without government programs; and

-- Low returns from government incentives to preserve wetlands relative to the profits from conversion.

In the last two years, two major changes in legislation and recent projections in the Appraisal (Department of Agriculture 1987) have combined to change the expectations associated with most of the above reasons. The changed expectations create the opportunity to conserve, and in some cases restore, wetlands thereby altering the trend toward further reductions in wetland acreage.

Legislative Changes to Conserve Wetlands

The Food Security Act of 1985 contained a "swampbuster" provision that disqualifies farmers who convert wetlands to agricultural use from participating in other USDA farm commodity programs. In addition to the prima facie effect of the provision, the provision also established the principle of "cross-compliance" as a major factor in the administration of resource management programs. Cross-compliance means that an action is enforced by establishing performance of the action as a criterion for qualifying for some other government benefit. The key is that the two actions or programs need not be directly related, only that they both affect the same people. For example, receipt of federally insured student loans by male college students is now contingent upon presenting evidence of draft registration. In the swampbuster case, continued receipt of crop subsidy payments is contingent upon not converting any more wetlands to agriculture. Now that the principle of cross-compliance has been accepted in the resource management area, it presents a host of additional opportunities for influencing private landowners' resource management decisions, such as adoption of BMPs for nonpoint source pollution abatement.

Appraisal Projections Provide Opportunities to Conserve Wetlands

The intermediate projections of the Appraisal are founded on several assumptions that run counter to the reasons, above, for wetlands conversion to

agriculture. For example, assumptions about increasing yields due to genetic improvement will mean that equivalent net returns can be obtained by farming fewer acres. Fencerow-to-fencerow planting using all available space will no longer be necessary, so wetlands need not be converted to increase output and income. The net result of the projections by 2030 is a 19-million-acre reduction in irrigated acreage, which reduces the need for new center pivot irrigation systems, and a 120-million-acre reduction in land farmed[1]. Both reduce the need to bring all available wetlands under cultivation. One way to help capture the opportunity that now exists to conserve forest and rangeland wetlands is to increase research efforts to help make the technological and policy assumptions in the Appraisal come to fruition.

Summary

Clearly, there are opportunities for changing watershed management practices on all ownerships and on all sizes of ownerships. Many principles and methods have already been developed; their consistent application is needed. Some landowners have not applied the principles and methods; additional education, technical and financial assistance are needed. Some opportunities need further research or recent research findings need additional work to develop practical solutions to problems; additional research and development work is needed. Only through coordinated efforts of all parties--private and public--can the use of water and related resources reach their full potential.

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Notes

1. The actual reduction in acres farmed from 1982 to 2030 amounts to a total of 160 million acres, 40 million of which are projected to be enrolled in the Conservation Reserve Program established under the Food Security Act of 1985.

Chapter 7

OBSTACLES TO IMPROVING THE MANAGEMENT OF WATER AND RELATED FOREST AND RANGELAND RESOURCES

The objective of this chapter is to highlight the most significant obstacles to improving the management of water and related land resources. The obstacles are not presented in any order of priority. Each one contributes to not being able to capture the opportunities presented in Chapter 6. Some of the obstacles identified can be altered by changing resource management policies, others will require new regulations or legislation. Some alternative ways of surmounting the obstacles are identified and methods of implementing them are suggested. The alternatives and methods discussed are not an exhaustive list.

The obstacles are:

— Water prices do not reflect the true cost to society of supplying water for agricultural use. Devising an acceptable transition from subsidized agricultural production to production where farmers' costs more nearly reflect the social cost of inputs, such as water, will be extremely difficult because the transition threatens major changes in agrarian lifestyles and the agricultural economy;

— Water institutions are giving high priorities to off-stream uses, to the detriment of in-stream uses such as fish and wildlife habitat and recreation;

— Information that accurately assesses current watershed and stream channel conditions and capabilities on all ownerships has not been consolidated. Further, the information available is often not displayed to managers in ways that they can use to evaluate management impacts or plan rehabilitation of watersheds in the worst condition;

— Private landowners lack incentives to implement BMPs to reduce nonpoint-source pollution;

— Income and property tax laws and regulations encourage wetlands conversion. There are few incentives to encourage private landowners to management wetlands for wildlife and recreation benefits to society; and

— Large-scale water yield augmentation entails significant environmental and social risks.

Water Prices in Transition

The projections of water shortages in Chapter 4, the implications of the shortages discussed in Chapter 5, and the opportunities for making changes outlined in Chapter 6 all point to the need for changes in current water resource allocations. But a major obstacle to making the changes in an economically efficient manner is that water prices often do not accurately reflect the marginal social benefit of providing or using the water. This leads to a misallocation of resources, from society's perspective, that needs to be redressed if crop production is to become more economically efficient on a national basis and projected water shortages are to be avoided.

Economic development of the West was water-driven. Between its formation in 1902 and the present, the Bureau of Reclamation has spent $8.7 billion constructing irrigation projects across the West (Shapiro and others 1988). Shapiro and others (1988) conclude that, today, longstanding ways of distributing water are being challenged and there is plenty of evidence that consumption restrictions and higher prices will occur unless new ways can be found to manage existing supplies. Colby and others (1988) reviewed current state legislation and regulations related to water markets and transfers. In the regions where shortages are projected, they concluded that markets have emerged and are functioning reasonably well. The obstacle to resolution of the contention documented by Shapiro and others (1988) stems largely from water price imbalances among uses whose correction threatens to alter the agrarian lifestyle favored by many farmers and other agricultural interests.
During the middle half of this century, and particularly in the 1950s and 1960s, the government strongly encouraged farmers to increase crop production. Among the public policies employed to stimulate production, western farmers were offered water from Bureau of Reclamation projects at prices that were substantially subsidized by the federal government. Further, if farmers produced more crops in aggregate than society demanded, the government bought the surplus at prices very near market prices. According to a recent Interior Department report, 38 percent of western farmland getting water from federally sponsored irrigation projects is used to grow crops that, because they are in oversupply, are eligible for federal subsidies (Shapiro and others 1988). Another example is that crops needing substantial amounts of water, such as hay and alfalfa for cattle feed, cotton, and rice, are being grown under irrigation in water-short areas when they could be grown in other parts of the U.S. at lower total social cost (when the government irrigation water subsidies are factored in).

Times are changing, and so are government policies. In this era of large federal government deficits, federal water resource managers and Congressional decisionmakers are reexamining fiscal priorities to determine if continued subsidization of irrigation projects and surplus crops is socially desirable. For example, the House Appropriations Committee provided no funding for new irrigation projects in the 1989 budget. The Appraisal assumptions include cessation of farm commodity programs for purchasing surplus crops and a reduction of 19 million acres (32 percent) in irrigated cropland by 2030. These kinds of actions foretell a major change in the agricultural sector of the U.S. economy; one that will not only affect farmers, but ripple through farm suppliers, such as manufacturers, distributors, and retailers of farm

implements, irrigation hardware, and fertilizer and agricultural chemicals, down to consumers of farm products. All will feel some effects of the adjustment; farmers in the regions where water shortages are imminent have already begun to experience the changes. Irrigated acreage has already dropped 1.9 million acres from its peak.

This is a classic economic case where what is good for a region or a locality differs from what is good from the national perspective. If one could ignore local concerns and do what is optimal for society as a whole, water and crop subsidies would be eliminated and the agricultural economy would wrenchingly adjust to the new socially optimal crop production pattern. But local concerns cannot be ignored.

It is difficult to deal with pending water shortages in an economically efficient manner from a national perspective. The major obstacle is lack of a politically acceptable transition from the current situation, where crop production is subsidized, to the new situation projected in the Appraisal, where subsidies are substantially reduced or gone. Until such a transition is developed, groundwater mining will continue at rates above long-term acceptable levels and in-stream uses of water will be under-supplied.

In-stream Uses Have Low Priority

The water budgets of Chapters 4 illustrate that of the four key variables affecting the water balance--precipitation rates, in-stream flow levels, rate of groundwater pumping, rate of off-stream consumption--only the latter three are under the manager's control. The manager takes what nature provides in the way of precipitation and chooses the levels of two of the latter three. Once the levels of two are chosen, the third one provides the balance.

In many states today, water managers chose the rate of groundwater pumping and the rate of off-stream consumption and let the in-stream flow levels provide the balance. The consequence is that in-stream flow levels are highly variable and may not always meet the flow requirements for optimal, or even good survival, habitat outlined by Tennant (1975). In dry years, groundwater pumping proceeds at the maximum rate and off-stream use slackens a bit, but in-stream flows drop way down. Some streams in the southern Great Plains, New Mexico, and Arizona dry up completely. In wet years, groundwater pumping slackens somewhat and reservoir refilling occurs to prepare for the next dry year. In-stream flows rise and balance the equation, but, like the runt in a litter, only after all other uses get their fill to make up for the previous dry year. Consequently, off-stream uses create externalities affecting fish and wildlife populations and recreation activities. This priority of operations is also reflected in the priorities for water uses. In Arizona, for example, the priority of water use has been established as (1) domestic and municipal supply, (2) irrigation and stock water, (3) mining and power generation, (4) recreation, wildlife, and fisheries; and (5) artificial groundwater recharge (Colby and others 1988). Off-stream uses first, then in-stream uses, and finally something to recharge the aquifers that are being overdrawn.

A Clash of Priorities is the Obstacle

Since the 1979 Assessment, there has been a surge in public interest in fishing and water-based recreation. The effects of cleaning up rivers and streams to make them fishable and swimmable again in response to the Clean Water Act has provoked increased interest in water-based recreation. Fishing participation continues to grow at a fast clip, according to the 1985 National Survey of Fishing, Hunting, and Wildlife Associated Recreation (Fisher 1988). Other water-related recreation activities also have enjoyed increases in participation.[1] However, near urban areas and especially in warm climates, summertime water-based recreation is booming. The question is, how will the projected increases in demand for in-stream water-based recreation be served by declining in-stream flows? The obstacle to meeting increased demands is the low priority given to in-stream flows compared to off-stream water uses.

Innovative Ways of Surmounting the Obstacle

It first needs to be ascertained whether or not social preferences among water uses have changed. The political process is one way of gauging changes. But it is often difficult to get a clear reading of social consensus on a particular issue from the political process because elections are rarely decided on a single issue and because they occur relatively infrequently. Markets are an alternative to elections for gauging social consensus. In markets, people vote with dollars and they vote frequently--each transaction is another datum instead of each election.

<u>The "Nature Conservancy" Approach--</u>Where the prior appropriation doctrine of water rights is used and markets for water rights are functioning, one method of gauging the consensus for increasing in-stream flows for recreation is to let the market function freely; that is, let interest groups purchase water rights and dedicate them to in-stream water uses. This approach is a water-based parallel of the kinds of land purchases the Nature Conservancy has been engaged in for years.

The Nature Conservancy acquires property, often at fair market prices, and dedicates it to management for recreational and preservation purposes. The Nature Conservancy manages some of the lands purchased, but also creates partnerships with public agencies to manage property purchased in ways meeting Conservancy goals. The Conservancy has often functioned as a third-party in purchases where a public agency wants to acquire a private holding; buying rights that are for sale when a land management agency does not have current appropriations for that purpose. In a subsequent year after receiving budget appropriations, the agency then purchases the property from the Conservancy and dedicates it to recreation and preservation purposes.

The markets for water emerging in the West are treating water rights more and more like real property. One way of providing more water for in-stream uses is to modify water rights laws and regulations to allow water rights purchases for the purpose of dedicating the water to in-stream uses. The modifications should explicitly declare maintenance and improvement of fish and wildlife habitat and water-based recreation to be beneficial uses of water. In addition, most state water laws currently declare that water must be used (off-

stream) or rights to it are forfeited. Where water is reserved for in-stream use, that water is reserved in the name of the state. So protections need to be added to the water laws to assure that water purchased by recreation interest groups will not be subject to re-appropriation by other off-stream users who want to put it to a "higher" or "more beneficial" use, and that in-stream water rights can be in the name of a party other than a state.

The "Multiple-Use" Approach--Reservoir operators in the Appalachian Mountains are receiving increasing numbers of requests for water releases to make possible certain kinds of recreation. The Corps of Engineers has been one of the leaders in timing reservoir releases to meet the needs of recreational water users. For example, special reservoir releases from Francis Walter Dam, built primarily for flood control on the Lehigh River in northeastern Pennsylvania, are made on weekends for 12 to 18 hours to create whitewater rafting opportunities. The schedule of releases is advertised well in advance, so both outfitters and private raft owners can make recreation plans. On the Savage River in western Maryland, national and international kayaking and canoeing competitions are held with special reservoir releases. Similar reservoir operating schedules have been implemented in Tennessee and north Georgia for rafting on the Ocoee and other rivers.

In setting up reservoir operation schedules such as these, environmental assessments should be conducted to evaluate the effects of short-term variations in flows. In some areas where fish and other aquatic organisms are suffering with poor survival habitat, flow variations of this sort may not have significant additional adverse effects.

Summary

A reconsideration of water use priorities is inevitable. Crop production is changing in response to market signals and public policies. Per-acre crop production potential is increasing faster than demand--that's the implicit Appraisal assumption behind the projected 120-million-acre decline in acreage farmed between now and 2030. As crop production changes in quantity and geographic distribution, so will the consumption of inputs to crop production such as water. As water use in agriculture changes, so will all the other uses of water. Fish, wildlife, and recreation should be freed from the constraints that relegate them to lower status than off-stream water uses, so that when water use changes occur, water markets can function freely to attain a social optimum.

Watershed Condition Assessments Require Better Information

Watershed condition is a concept that has been discussed in general terms for years. However, only recently has the concept been translated into a practical definition usable in land management, Chapters 1 and 6. Three condition classes have been identified that link management goals and the land's current condition and capability to meet the goals. Two major management uses of watershed condition classification are for evaluating the amount of erosion likely to be created by use and assigning priorities for watershed rehabilitation and restoration project planning. But before land managers can

use watershed condition classifications for these purposes, current land condition and capability information must be available. Stream channel types and conditions should also be described. Only then, can site impacts from use be evaluated and planning priorities be assigned.

The obstacle to using watershed condition classifications in land management evaluation and planning is that information on current land condition and capability and stream channel types and conditions is not available for all areas.

Resource Inventory Data Must Be Clearly Presented

The U.S. Department of Agriculture conducts several different kinds of inventories that provide useful information to resource managers. Some inventories provide information on a regional basis. The Natural Resources Inventory (NRI) is conducted by SCS every five years. It provides a snapshot of land uses and related information, focussed primarily on crop and forage production. The Forest Service conducts resource inventories of forest and rangeland across the U.S. Inventory cycles range from 10 to 15 years, depending on the region, with mid-cycle updates based on subsamples. The focus here is on vegetation cover types and production levels. These inventories provide useful information for this Assessment and the Appraisal, but the data is too general for use by land managers contemplating specific projects in particular watersheds.

Data Coverage is Incomplete at Places--The National Cooperative Soil Survey (NCSS), led by SCS, conducts soil surveys that provide watershed managers with much useful information on soil types, textures, and other essential information. Federal agencies, such as the Forest Service, conduct soil surveys and related land resource inventories on public lands, following NCSS standards. Although soil surveys have been conducted since the beginning of the 20th century, complete coverage has not been attained. Because the focus of soil surveys has been on the crop and pasture land, the gaps in coverage fall most heavily on private forests and rangeland. Where land cover types have been changing from crops and pasture to forests, such as occurred in the South in the early part of this century, soil survey coverage of forest land is better than in other regions. Nevertheless, the lack of complete coverage of counties where forests or range predominate is a hindrance to implementing and using the watershed condition classification.

Where Coverage is Complete, Data is Unconsolidated--The land capabilities and current situations on many sites have been evaluated by field personnel of various federal, state, and local agencies. For example, SCS District Conservationists and county extension agents know the current situations and capabilities of the lands and streams in their areas. On each national forest, a Watershed Improvement Needs inventory is periodically conducted. The major problem with the present practice of performing capability and situation evaluations on a decentralized basis is that it is difficult to present a consolidated summary of information for the entire watershed. Consequently, land managers have incomplete data for assigning project priorities. Decisionmakers have only partial information for balancing watershed

improvement needs against other resource management needs when allocating budgets.

A major reason for this inability to consolidate data on a watershed basis is the patchwork-quilt distribution of landownership within a watershed. One or two locations creating problems in a watershed that is otherwise in fine shape can adversely affect water quality and constrain use of the total flow coming from a watershed. So differences in landownership and associated differences in the mission of agencies serving different types of landowners, create an obstacle to evaluating impacts, setting priorities, and attaining water quality goals on a watershed-wide basis.

The first step toward surmounting this obstacle is to find a way to consolidate, standardize, and display data already collected for different land ownerships by different agencies at different levels of government. The objective is to lay the foundation of data needed to coordinate solutions to watershed problems and build partnerships among landowners and agencies offering technical and financial assistance to implement them.

Geographic Information Systems (GIS) may be able to help in this process. The key is finding a way to standardize data collected by different entities for related purposes over parts of watersheds into a single overlay for the entire watershed. Until this becomes possible, it will remain difficult for managers to evaluate cumulative effects and assign priorities. GIS will not make existing information better. But it will make the data more usable by providing a mechanism for storing and displaying consolidated data. Having the mechanism provides the impetus to consolidate data already collected by different agencies.

Significant strides have been made in the past two decades in using aerial photography and remote sensing to map overstory vegetation. Advances have also been made in using these techniques to distinguish among some soil characteristics, such as moisture, because of their influence on light reflectivity. For example, the extent of wetlands along stream channels or reservoirs can be mapped using photography or remote sensing. Preparing maps this way reduces the cost and time of field labor because instead of collecting all the data needed to prepare maps, the maps already prepared based on photography and telemetry only need to be verified. Similarly, some differentiation among forest cover types has been achieved based upon leaf reflectivity. Although aerial photography and remote sensing provide complete geographic coverage of the U.S. and geographic resolution is approaching acceptable levels for GIS proposed by state and federal resource management agencies, these methods of data collection still are not capable of providing all the details on mid-story and understory vegetation or on soil and stream channel characteristics needed by watershed managers in a condition classification system.

The consequence of not having consolidated data for all landownerships is that decisions on watershed rehabilitation and restoration priorities will be made based only upon the ownerships for which information exists. Because coverage is incomplete, it cannot be determined if expenditures targeted on the areas

with known problems will provide the largest possible improvement in overall watershed and water quality.

Soil Survey Work Should be Completed Expeditiously--Additional work is needed to gather complete soils and stream channel information on forests and rangeland. For example, about 80 percent of the soils inventory on national forest is completed. The inventory needs to be completed without delay, emphasizing information necessary to make management decisions concerning soil, site, and water productivity and impacts of site use. Additional work is also needed on how to summarize and display the information collected, beyond building GIS overlays, so that it can contribute to management decisions. This work is only getting started. Watershed managers and decision makers need to play a stronger role in this work than they have in the past. They need to articulate the kinds of decisions they expect to make based on the watershed condition classifications and data. Then, data analysis and presentation procedures must be developed or updated to meet their needs--no small task.

More work is needed to test the validity of information already collected. Validation is likely to be a difficult research task. Validation presupposes that a clear cause-and-effect relationship already has been developed between the soil, site, or vegetation characteristics and the project- or activity-related impacts, such as erosion or water flow regimes, that watershed managers hope to evaluate. If these relationships have not already been developed through research, they are a necessary precondition to developing inventory sampling and data validation procedures.

One of the primary beneficiaries of better watershed-level information will be nonpoint-source pollution control and erosion modelling work. Because sediment is the primary nonpoint pollutant from forests and rangeland, in terms of volume, watershed condition information related to soil type, texture, and erodibility are key needs. A multi-agency task force of U.S. Department of Agriculture experts has begun work on the Water Erosion Prediction Project (WEPP). WEPP's goal is to improve prediction of surface erosion and sediment yield and their on- and off-site impacts. It is hoped that the WEPP model will replace the Universal Soil Loss Equation, developed in the 1950s for agricultural land, for predicting forest and rangeland erosion and impacts. The WEPP framework includes elements for surface erosion, sedimentation-slope relationships, off-site damage, channel routing and stability, mass failure rates, and watershed condition. The kinds of data discussed in this section will be needed to project these WEPP elements. Ways need to be explored to merge WEPP information with the data analysis, consolidation, and display tasks already discussed.

Private Landowners Lack Incentives to Use BMPs

Nonpoint-source pollution has emerged as a major problem in many areas, now that major point-sources have been cleaned up. Sediment is the major nonpoint-source pollutant from forests and rangeland. Undisturbed, mature forests generate very low annual sediment loads--less than 0.5 tons per acre. Disturbances are caused by most typical management activities, each of which has a different potential for causing nonpoint-source pollution. Road

construction, harvesting, fire, and preparing for regeneration are the primary activities causing nonpoint-source pollution. Average erosion rates for well-managed logging activities may be fairly low, perhaps only an additional ton per acre per year. But erosion rates of 10 to 15 tons per acre per year are not uncommon for harvesting activities. Intensive mechanical site preparation before treeplanting can generate sediment at rates exceeding 100 tons per acre per year (Dissmeyer and Stump 1978). In the past decade, managers have become more aware of the adverse effects that some mechanized activities, such as root-raking, can have on soil productivity and sediment loss. Many of them are not as widely used today as a decade ago.

BMPs Are Known

Research has successfully identified major causes of sediment production. Practical procedures to reduce sediment production and mitigate sediment damages have been developed. WEPP is producing predictive models that will help managers evaluate the likelihood of environmental damage to a specific site from various activities. Thus, silvicultural and range-related BMPs are known and the ability to predict effects is being developed.

Why, then, are some landowners not using BMPs when engaged in soil-disturbing activities? There are three obstacles to using BMPs. The first is that erosion is an externality, so the market provides little or no incentive to use BMPs. The second is that employing BMPs is often not in the economic self-interest of a landowner. The third reason is that knowledge about BMPs has not been effectively transferred to all landowners.

Erosion Is An Externality—Erosion as an externality was discussed in Chapter 1. Sediment typically imposes few short-run costs on a landowner; operating savings may even occur if no attention is paid to sediment generation. For example, two and three decades ago, if a skidder could be driven back and forth across a stream without bogging down, it was. By doing so, the cost of installing culverts or building a bridge was saved. The fish habitat destroyed or the cost of added water treatment by downstream municipalities did not show up on the landowner's ledger. Thus, the landowner was not bearing the full costs of his land management decisions. Libby (1985) noted that there is no incentive for an individual to personally bear the cost of producing benefits for others. Motivated by the Clean Water Act, state governments are now intervening in the market and establishing legislation and regulations to levy civil and criminal penalties for creating nonpoint-source pollution. Incentives are being created that force those creating the problem to bear fiscal responsibility for sediment production.

Using BMPs Costs Money—In spite of the existence of laws and regulations, some landowners are not using BMPs. Myer and others (1985) noted that adoption of only some BMPs is in the self-interest of landowners and equipment operators. For example, using BMPs to construct properly logging roads intended for long-term use can produce savings, both in terms of lower road maintenance costs as well as in lower repair rates for vehicles using the road. In most cases, however, using BMPs is not in the economic self-interest of the owner or operator.

There are two ways to alter the situation where using BMPs costs the landowner more than they provide benefits--the "carrot" and the "stick" approaches. The "carrot" approach uses financial incentives to make it more profitable for landowners to use BMPs. Cost-sharing and income tax credits are the two current vehicles available. To encourage more widespread use of BMPs, the funding level for incentives should be increased. Not only should more landowners be able to participate, but the economic benefit per landowner should also be increased.

To use the "stick" approach, the cost of not employing BMPs should be increased. There are two elements to this approach--the penalty for getting caught not using BMPs and the likelihood of being prosecuted and found guilty. Both elements enter the landowners decision whether or not to pay the added cost of using BMPs. Increasing the aggressiveness of enforcement increases the likelihood of getting caught and makes the paying the financial penalty more certain. Increasing the financial penalties is the alternative. Increasing enforcement usually costs the government money and goodwill, whereas increasing the fines for lack of compliance results in financial returns to government. Now that cross-compliance has been adopted as a mechanism for levying penalities in the agriculture land use sector, it may also prove an effective means of securing use of BMPs in the silviculture and range management areas too. For example, eligibility for forestry incentive payments should be contingent upon using BMPs.

Whether to use the "carrot" or the "stick", or a combination of the two, is a decision involving aspects of public administration, public policy, and politics. For example, regulatory programs (the stick approach) are popular in the West where the number of forest landowners are relatively few and the size of their holdings makes BMPs more affordable. Incentive programs are more popular in the South, where the number of forest landowners is large and the average size of individual holdings is small. There, BMP costs are more difficult for an individual to absorb and the cost of enforcing regulations among a large number of small landowners is both administratively and politically difficult.

<u>Some Landowners Lack the Knowledge to Implement BMPs</u>--Forest and range landowners tend to perform soil-disturbing activities at infrequent intervals. Many forest landowners only harvest timber every 10 to 15 years; for some, once in a lifetime. In addition, many landowners undertake timber harvesting or range rehabilitation without obtaining assistance from either private consultants or public servants. Consequently, the unknowing landowner does not take the necessary steps in both project planning and project supervision to avoid nonpoint-source pollution.

Sorenson (1985) reported that information programs for nonpoint-source pollution abatement were then in a pioneering stage and that much remained to be learned. But his experience with one of the earliest programs, in Wisconsin, provided the following insights:

-- Identifying the specific objectives of the information program is a key element. While the ultimate objective is reducing nonpoint-source pollution, identifying more detailed objectives for information program elements is essential.

-- There is usually more than one audience; each has different needs. The community in general is usually one audience, separate and distinct from the specific landowners creating pollution problems.

-- It usually takes more funding and more time than planned to develop an effective program; one whose success can be evaluated in terms of on-the-ground results.

-- Any information and education program will be a cooperative effort among federal, state and local agencies. Preparing written agreements outlining the role of each cooperator, updated every few years, will assure that gaps and overlaps in outreach efforts will be minimized.

-- Plan a variety of activities to reach everyone in the target audiences.

-- Evaluation is an important, albeit difficult, part of the information and education program. Finding out what works and what does not is the only way to make the program more effective. Deciding on the measures of success is often one of the most difficult aspects of conducting a program evaluation. Consultants can be of assistance in this phase.

Because agricultural activities are a much larger component of the nonpoint source pollution problem than silvicultural activities, information and education programs targeted at agricultural audiences may already have been developed in some states. Agencies concerned about silvicultural nonpoint-source pollution may be able to become cooperators with the agencies having ongoing agricultural information and education programs. Alternatively, the agencies concerned with silvicultural nonpoint-source pollution will be able to learn from the experiences of those serving the agricultural community if a separate silvicultural program is warranted.

Summary

Wilson (1985) discussed the provisions of the Oregon Forest Practices Law and how it is being implemented to reduce silvicultural nonpoint-source pollution. His description demonstrates the importance of information and education efforts and how they can be combined with rules and enforcement procedures into an integrated program to maintain forest productivity. State agencies are the logical institutional units to coordinate programs to implement BMPs. Federal agencies need to be ready to provide financial and technical assistance to help states design programs. Federal agencies also should be ready to help deliver assistance to landowners during program implementation. A coordinated institutional approach will give private landowners the incentives needed to use BMPs and help the state-run programs achieve consistency with national nonpoint-source pollution abatement goals.

Current Laws Encourage Wetlands Conversion

There are two major categories of tax incentives to convert wetlands to "higher and better" uses, such as crop production and urban developments--income tax laws and regulations and property tax laws and regulations. The income tax code operates primarily at the federal level. State income tax laws often contain the same provisions encouraging wetlands conversion as the federal code. Property tax laws are commonly enacted at the state level and enforced at the local level.

Income Tax Encouragements

The income tax code provides deductions for all types of general development activities and are the most significant federal incentive for farmers to clear and drain wetlands. The result is that a significant portion of the costs of wetlands conversion costs are shifted to the general taxpayer. The dollar value of the tax incentives is higher at higher income levels. The Office of Technology Assessment (1984) listed four major incentives to wetlands conversion. The 1986 changes in the income tax code altered two of them. The four incentives mentioned were:

-- First-year tax deductions of up to 25 percent of gross farm income are allowed for draining expenses. Expenses in excess of this limit may be deducted in subsequent years.

-- Tax deductions are allowed for depreciation on all capital investments necessary for draining or clearing activities.

-- Tax deductions are allowed for a portion of the interest payments related to draining and clearing activities. The 1986 changes in the income tax code provide for gradually phasing this deduction out, unless the interest is on a home equity loan.

-- Investment tax credits equal to 10 percent of the installation cost of the drainage tile are allowed. The 1986 changes in the income tax code eliminated this tax credit.

Property Tax Encouragements

Property taxation encourages the conversion of wetlands through the process of determining the assessed value of a parcel. Wetlands are commonly not used for any income-producing purpose, hence their assessed value is low. When wetlands are put to an income-producing use, their assessed value is usually increased. When the assessed valuation increment is big enough that the tax increase makes the income-production process no longer financially attractive, landowners are put in the position either of discontinuing the activity or selling the land.

Property assessment guidelines are commonly quite broad and general. In the hierarchy of uses, land used for business purposes is often assessed a higher

value than land used for private purposes. Further, the assessment guidelines make it easier to raise assessed value than to lower it.

Here is a generic example of how property tax administration has often encouraged wetlands conversion. A farmer has a wetlands on his farm. The assessment guidelines do not provide for unproductive areas in fence rows and similar land to be subtracted from producing acres when the assessment is conducted. The assessor rules that the wetlands shall be treated the same way as fence rows. So the farmer winds up paying several hundred dollars in taxes each year on land that produces no income. In the occasional bountiful year, the farmer takes advantage of the income tax rules and spends some his added income on draining a portion of the wetlands. Over time, the entire area is drained and converted to crop production, producing income. Repeated thousands of times annually across the U.S., the net result is losing several hundred thousand acres of wetlands per year.

Reducing the Incentives

There are direct approaches to reduce the incentives to convert wetlands and indirect approaches. The direct approaches involve changing tax codes and property assessment guidelines. The indirect approaches are like cross-compliance; let the tax incentive remain but add a penalty of some other sort that reduces the usefulness of the incentive or increase a payment providing a counterincentive to the tax incentive.

<u>Change the Income Tax Code</u>--The direct approach of changing the income tax code to disqualify wetlands conversions has not been used. Legislation declaring that the cost of converting wetlands is ineligible for deduction or amortization is the kind of precise remedy that has a reasonable chance of passage. The key is whether or not a political consensus could be mustered that preserving wetlands is socially desirable. Alternatively, a provision establishing a new tax credit for retaining and restoring wetlands, much like the forestation or reforestation tax credit, would also work. The approach would be to compensate the landowner for the additional tax burden borne by keeping the wetlands as wetlands. The political efficacy of this approach is judged much less than the former proposal.

The 1986 changes to the federal income tax code consolidated incomes brackets into three broad brackets and lowered the marginal tax rates for higher incomes. The net result is that the lower marginal tax rates reduce the benefit of converting wetlands to other uses because the deductions are no longer worth as much to the taxpayer. Another provision in the 1986 changes reduced the deductibility of consumer loan interest, unless the loan is tied to property equity. This may have some effect on the willingness of farmers to borrow money to drain wetlands. The investment tax credit formerly available for installation of drainage tiles was abolished by the changes in the law.

<u>Change the Property Tax Code</u>--The direct approach of changing property taxation regulations hinges on modifying assessment valuation guidelines. Changing laws and guidelines state by state takes time. It took several decades for the current use valuation principle to become widely applied to forestry. That principle asserted that where a certain land use was deemed socially desirable,

such as forestry, that so long as a landowner kept the land in trees--irrespective of its potential value in some other use, such as cropland or industrial development--the land's value should be assessed as forest land. The first step in securing use valuation for wetlands is to attain consensus that wetlands are socially desirable and get that preference written into law. The second step is to get the assessment valuation guidelines modified so that surveys recognize the presence of wetlands and assess their value accordingly.

Indirect Approaches--The indirect approach has been the preferred approach to date. The swampbuster provision of the Food Security Act of 1985 is the latest provision. It reduces conversion by denying eligibility for federal farm benefits to those growing agricultural crops on wetlands whose conversion began after December 23, 1985. It is important to note that this provision does not protect wetlands nor prohibit drainage or modification. It is too early to tell what effect this provision is having on the wetlands conversion rate. Recent market conditions for agricultural commodities make conversion unprofitable and so swampbuster may slow conversion (Feierabend and Zelazny 1987). If converted wetlands are not used to grow crops subsidized by the government, no penalty ensues. The effectiveness of swampbuster will not be tested until crop prices recover and it once again becomes profitable to convert wetlands to boost crop production.

The 1977 amendments to the Clean Water Act provided language giving the Corps of Engineers rulemaking discretion to include wetlands within the Section 404 program.[2] The Section 404 program gave the Corps responsibility for regulating the discharge or disposal of dredged or fill material. The Corps views its primary function in carrying out the law as protecting the quality of water. Although wetlands values are considered in reviewing project permits, the Corps does not feel that section 404 was designed specifically to protect wetlands (Office of Technology Assessment 1984).

The 404 program provides a major avenue for federal involvement in regulating activities that use wetlands. But it was not designed to stop the conversion of wetlands to other uses. The 404 program only regulates the discharge of dredged or fill material onto wetlands. Projects involving drainage, clearing, or flooding of wetlands are not explicitly covered in the legislation; hence are not regulated directly by the Corps. Thus, instead of preventing wetlands conversion, the thrust of the program is to prevent water quality degradation from some activities affecting wetlands. The consequence is that some wetlands conversions have been avoided, but the extent is difficult to estimate. Office of Technology Assessment (1984) concluded that without more direct government involvement, the conversion of most inland wetlands is likely to continue unabated. It appears that the swampbuster provision of the Food Security Act of 1985 was a Congressional response to the above conclusion.

The 404 program provided some disincentive to convert wetlands. In 1981, the acreage affected by permits requested totalled about 100,000 acres. As ultimately approved by the Corps, the acreage affected totalled about 50,000 acres (Office of Technology Assessment 1984). Of approximately 11,000 permits received annually, about 3 percent are denied, about 14 percent are withdrawn by applicants, about one-third are modified significantly and about half are approved without significant modifications. Other federal agencies, such as

the Fish and Wildlife Service, can participate in the permit review process; EPA has veto power over permit approvals. The National Marine Fisheries Service of the Department of Commerce estimated that the 404 program, in combination with state programs, reduced coastal wetlands conversion by 75 to 80 percent in 1981. EPA has only used its veto power less than a dozen times between 1977 and 1984 (Feierabend and Zelazny 1987).

There are four principal nonregulatory programs that help protect wetlands. Most of these involve land acquisition and are designed to protect wetlands from drainage and destruction through purchase or lease. The 1929 Migratory Bird Conservation Act authorized federal acquisition of land for migratory waterfowl refuges. The 1934 Duck Stamp Act established a source of funding for the Migratory Bird Conservation Act through sales of federal migratory bird hunting stamps, called "duck stamps", to all hunters aged 16 and older. The funds collected are used to acquire habitat for migratory waterfowl, including both wetlands and related uplands areas used for nesting and cover. Since enacted, the duck stamp program has generated nearly $313 million, used to acquire more than 2.3 million acres (Feierabend and Zelazny 1987).

The Wetlands Loan Act of 1961 was intended to accelerate federal acquisition of migratory waterfowl habitat. The law, extended through 1988, authorized additional federal appropriations as a loan against future revenues from duck stamp sales. As of 1985, more than $190 million had been appropriated for acquiring additional habitat.

The Land and Water Conservation Fund was established in 1964 and also provides money for land acquisition financed by receipts from offshore oil and gas revenues. The legislation establishing the Fund authorized Congress to appropriate up to $900 million annually. Annual appropriations have always been a fraction of the authorized level. As amended by the Emergency Wetlands Resources Act of 1986, the Fund can also be used to acquire wetlands. The Act also requires states to include acquisition of wetlands as part of their statewide comprehensive outdoor recreation plans. The 1986 Act also raised the amount of money going into the Migratory Bird Conservation Account.

The Water Bank Program is administered by the Agricultural Stabilization and Conservation Service. The program authorized $10 million per year for 10-year leases for waterfowl habitat from private landowners. This program has not received much money in recent years. As of April 1987, the program had funded 4,615 leases, protecting 153,073 acres of wetlands and 332,861 acres of adjacent uplands (Feierabend and Zelazny 1987).

<u>Summary</u>--The slow grinding of the political process is a factor in implementing of any of the tax code changes or expanding any of the indirect approaches for halting wetlands conversion. The process will not speed up unless a political consensus emerges that additional federal help is needed to conserve wetlands. It may be easier to secure the consensus needed at the state level for changes in state legislation.

Many of the nonregulatory vehicles available have stood the test of time as effective ways of conserving wetlands. With additional appropriations to the

programs, more could be done without significantly expanding the bureaucracy needed to implement the programs.

Environmental and Social Impacts of Large-Scale Water Yield Augmentation

The three water yield augmentation measures identified as ways of capturing opportunities in Chapter 6 are vegetation management, snow trapping structures, and weather modification, primarily through cloud seeding. The efficacy of each of these measures for increasing water yields has been demonstrated in pilot tests. But they have never been implemented on the scale necessary for capturing the opportunities discussed in Chapter 6. The environmental and social impacts of using these measures on a large scale constitute the largest obstacle to using them in a coordinated way on a regional basis.

The cumulative nature of the impacts generated to make a significant contribution to regional water yields is what makes them important. Just employing the measures in a single watershed will be insufficient. Most of the watersheds in the Upper Colorado region will have to be managed for water yield, if projected water shortages in the Upper and Lower Colorado regions are to be alleviated. Consequently, the implicit tradeoff being considered is to mitigate major impacts in the social structure of agricultural communities along the middle and lower portions of the Colorado River basin by making major alterations to the environmental and social character of forest and rangeland management in the headwaters of the tributaries to the Colorado River. The objective of this section of the report is to outline some of the impacts likely to occur in the headwaters to provide a better foundation for evaluating the role of water yield augmentation in alleviating projected shortages.

Environmental Impacts

Implementing the three measures over wide areas will create significant environmental impacts. The focus here is on the two major components: a significant increase in timber cutting[3] and stream channel integrity.

<u>Timber Cutting Will Increase</u>—Vegetation management relies upon a reduction in evapotranspiration as a major vehicle to obtain yield increases. Cutting timber in the correct pattern can improve the ability of an area to trap snow and delay snowmelt into early summer but does little to increase total regional flows.

Some level of clearcutting will be necessary to provide the patchy cover necessary to trap blowing snow. Thinning will also be needed to regulate the amount of shade and timing of snowmelt. At the altitudes where this cutting is needed, soils tend to be more fragile and unstable than at lower elevations. Consequently, any type of cutting that increases the amount of water in the soil increases the hazard of mass failures (landslides). The likelihood of increased numbers of landslides must be considered when evaluating the feasibility of a major regional commitment to water yield augmentation, as well as during project-level planning, such as for road and timber-cutting layouts. If soils were consistently stable or consistently unstable, it would be easy to deal with the issue of whether more landslides will occur. But the fact is

that soil stability in high-elevation watersheds tends to be quite variable. Thus, planning and decision-making is all the more difficult.

After timber cutting, ecological succession begins. Water yields usually stay high until trees are reestablished on the site and their crowns close. Delaying crown closure will pay benefits by keeping water yields elevated. Fire and herbicides are the two most common practices used to retard ecological succession. For example, chaparral needs to be burned every 12 to 15 years to keep water yields high. Although fire is relatively inexpensive, the difficulty with using it on slopes is retaining enough vegetation on the site to keep the soil anchored in place. That usually requires a light, fast burn; one that can easily overrun the prescription boundaries. Herbicides and application rates can be chosen that will kill some plants but not others. For example, products have been developed that will kill broadleaved plants, but only stunt grasses. These herbicides have become quite popular in right-of-way maintenance beneath utility lines and along highways. A single herbicide treatment each year has reduced the frequency of mowing highway medians from 8 to 10 times annually to 2 or 3 times, yet the grass remains effective in preventing erosion. Thus, using herbicides can reduce the likelihood of sediments polluting water supplies.

A benefit from using vegetation management to augment water yields is that a more diverse vegetation structure is created. Clearings will be interspersed with areas thinned and areas where no cutting has occurred. Large amounts of edge will be created. Thus, the area will provide habitat for a wider variety of wildlife. Adequate cover for concealment and for protection from heat and cold will also remain. So larger numbers and a wider variety of wildlife are expected from a more diverse vegetation structure.

The objective of the cutting patterns is to alter the wind flow so that snow falling in the cutover areas is blown into and trapped by the thinned stands. The clearcut patches will create changes in wind patterns up to several hundred feet off the ground. Currents will be changed and eddies will form. The consequence will be increased hazard of windthrow damage. Trees along the edge between cut and thinned areas on the upwind side will be most susceptible to swirling gusts. Early season snowfalls before the ground is frozen or late spring snowfalls where the snow is wet and heavy create the most risk of windthrow.

Finally, vegetation management to augment water yields is expensive. Many of the watersheds that feed headwaters of tributaries to the Colorado River are public land. Given recent Forest Service budget levels, it is not possible to fund vegetation management on the scale described. New partnerships must be created whereby the beneficiaries of the additional water would help pay to create and maintain flows from national forests.

<u>Stream Channel Integrity Will Be Threatened</u>--Stream channels have evolved based upon historical patterns of precipitation and runoff. When major increases in precipitation and runoff occur, the higher flows will create environmental impacts. If the timing of snowmelt is not extended, flood peaks will rise as will water velocity. Higher peak flows will increase flood damages to residents along valley bottoms. Higher flow rates mean that the water has more

energy to carry sediment. Increased bottom scour and bank erosion is the result, leading to increased sediment damages downstream.

The objective of the cutting is to extend the duration of snowmelt, so flows are higher longer into the summer. The major impact on stream channel integrity will come if the winter and early spring weather varies significantly from its long-term average; which is almost certain on occasion. If wintertime precipitation is abnormally heavy and if the spring thaw is abnormally rapid, then flows will rise rapidly to a peak well above the norm and velocities will also be high. Even the best timber cutting patterns cannot overcome abnormally warm air temperatures. Weather modification plans must take into account stream channel capacities in the event of a sudden warmup, and not add more snow to a basin than stream channels can reasonably handle.

Despite the research that has been conducted, weather modification remains an inexact process. Seeding has been used in recent years to augment snowfall for skiing. But difficulty in controlling where the snow falls has reduced the acceptability of the technique. The increased snowfall cannot be confined to a single watershed. Snow often continues to fall well past the target area. For purposes of water yield augmentation, targeting is less of a problem. All the melt water will still wind up going down the same stream.[4]

Other Environmental Impacts--Research has demonstrated that snow trapping structures can be used above timberline. Alpine and tundra ecosystems are much more fragile than ecosystems at below timberline. The impact on vegetation from constructing fencing 15 to 20 feet tall would be severe. Fencing will need to be anchored solidly to withstand severe winds and constructed of materials that will withstand the elements. The need, and impact, of maintenance on the fencing should not be underestimated. When all these factors are considered, fencing will probably not become as popular for solving regional water shortages as vegetation management and weather modification. However, fencing will continue to play a prominent role locally in keeping snow off highways and in range management, for filling isolated depressions for stock and wildlife watering.

Sites undergoing vegetation management to increase water yield need to be tended on a more frequent schedule than conventional timber management. Crews will be working on sites every few years. Although such schedules are acceptable in the South for managing southern pine, it is not known if the more intensive management schedule, such as burning or herbicide applications every several years, will be acceptable in the Rocky Mountains.

Social Impacts

Vegetation management, weather modification, and snow fencing create social impacts. Political impacts are a component. Certain of these impacts are tangible in the sense that they can either be mitigated or compensated with dollars from the regions who use the added water. Other impacts occur, however, where neither mitigation nor compensation may be feasible.

Large-scale vegetation management will cause visual impacts. Unless the layout of the cutting patterns is done with skill and sensitivity, the mid- and long-

distance views of the mountains will be adversely affected. Irregular shapes that blend in with terrain features are least objectionable. Computer programs exist that enable landscape architects to lay out the cutting patterns and model how the views will look after cutting. Whether the views will be socially acceptable is unknown. To the extent that structures are used above timberline, these may create additional visual impacts.

Weather modification creates additional snow in both rural and developed areas alike. Public reaction to current weather modification practices is mixed. Concerns have been expressed about the ability of the roof structures of residential dwellings to carry the weight of additional snow loads. More snow requires local governments to spend more to keep roads cleared. Economic costs such as these need to be counted when partnerships are formed to provide for interbasin transfers of water. The social impacts include living with more snow in winter and for a longer season.

The additional water provided from public lands is subject to appropriation. Forest Service policy is to provide the water for other political entities to distribute. The competition among political jurisdictions and interest groups to appropriate the increased flow of water will be keen. Conflicts among competing uses are likely to emerge. Additional reservoirs will be needed to capture the most benefits from the increased yield; generating additional environmental, social, and economic impacts. The unanswered question is who will pay the costs of vegetation management, weather modification, and associated water developments? In the early decades of this century, the federal government would have played a major role each step of the way. In the past decade, federal participation in water resource developments has shrunk. Partnerships between local, state, and federal governments are now needed--with the local and state interests picking sharing a much bigger portion of the costs than in earlier decades. The partnerships are yet to be formed. The social and political compacts needed to reach a consensus on how to deal with projected shortages do not exist. Whether the linkages can be forged, at what cost, and who will pay remain to be seen.

Summary

The focus in this chapter has been upon the six obstacles having the most severe and direct consequences upon forests and rangelands and their associated wetlands. Obstacles to managing water resources and related lands that are not forests or range have not been explored here, although many do exist. Removing some of the obstacles discussed here , such as making water markets freer or giving in-stream uses higher priority will undoubtedly have effects upon other uses and obstacles as well.

The goal of this chapter, and the preceding one, has been to stimulate thought about how to manage water and related lands in the near future. To realize opportunities and overcome obstacles will require changes in recent trends of water and land resource allocations and in the institutions that manage the resources. Whether or not we as a nation choose to follow recent trends and endure the likely implications outlined in Chapter 5, or move to a different future, perhaps realizing some of the opportunities and removing some of the

obstacles discussed in the last two chapters, requires conscious decisions on the part of society and land managers. One vehicle to engage society in considering these kinds of decisions is to outline potential changes in government programs for managing water and related land resources. Then, through discussion of the proposed program changes, managers and members of society can interact, and begin to build a consensus about future management directions. The 1990 RPA Program will discuss potential strategies for managing water and related land resources on national forests, for assisting states in watershed management, and for conducting research in these areas. To build a linkage to the Program, the implications of the findings of this water assessment for current and future Forest Service programs are the subject of the next chapter.

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Notes

1. See the Analysis of the Wildlife and Fish Situation: 1989 - 2040 (Flather and Hoekstra 1988) and the Analysis of the Outdoor Recreation and Wilderness Situation: 1989 - 2040 (Cordell 1988), companion technical documents supporting the 1989 RPA Assessment for additional information in increases in fishing and water-related recreation participation rates.

2. A 1975 decision by the U.S. District Court for the District of Columbia, in Natural Resources Defense Council versus Calloway broadened the scope of the original 404 program from the Corps' traditional definition of navigable waters (emanating from the 1899 Rivers and Harbors Act) to "all waters of the United States." The issue of the Corps' jurisdiction was hotly debated, but left unchanged in a close vote, when the 1977 amendments to the Clean Water Act were passed.

3. Timber cutting is used here instead of timber harvest, because harvest implies that the trees cut are a merchantable product, when in fact, they may have little or no market value. Merchantability is affected by may things, including tree diameter, species, and the location of the stand in relation to the nearest mill. Increasing the water yield from the site, not obtaining returns from harvesting timber, is the primary land management objective.

4. In Colorado, much of the water used to supply residents east of the Front Range, who live in the Missouri and Arkansas-White-Red regions, comes across the Continental Divide from the Upper Colorado region. These trans-region diversions are ignored in the referenced sentence.

Chapter 8

IMPLICATIONS FOR WATER AND RELATED FOREST AND RANGE MANAGEMENT PROGRAMS

The economic, environmental, and social implications in Chapter 5, the opportunities outlined in Chapter 6, and the obstacles discussed in Chapter 7 suggest ways that water and land management programs can alter the future situation projected in Chapters 2, 3, and 4. Many of the changes have implications for programs of other federal agencies, of state agencies, and of local organizations. Although some of these implications will be mentioned in this chapter, the main focus is on implications for Forest Service programs.

Forest Service program implications of the water assessment findings are presented as answers to six questions. The questions provide a structured way of exploring the impact of assessment findings on how the Forest Service manages national forests, provides assistance to States and private landowners, and conducts research. Similar questions are being asked in the minerals, recreation, and timber assessments as a way of strengthening the link between assessment findings and the 1990 RPA Program.

Question 1: What should the federal government do to ease potential future shortages of water and other watershed resources?

Potential future shortages arise because a gap is projected between future supplies and future demands. If the government does not intervene in the market, the economy will function and prices will rise until demand and supply are equal. Rising prices will reduce demand. They also will provide incentives to boost supplies.

In some cases, allowing prices to rise high enough to equilibrate demand and supply results in price increases judged socially inequitable. Then, government could intervene in the market to curb demand, such as by implementing rationing, or to increase supplies, such as by sharing the cost of forest regeneration. In addition, government actions may be used to redistribute impacts. For example, rationing allocated the resource without regard to a user's ability to pay.

In the past, all three levels of government--federal, state, and local--have borne responsibilities for easing water shortages. The traditional response of the federal government to shortages has been to increase supplies, not to restrict demand. The federal government has intervened to help develop water resources using dams and conveyance structures and has played a role in the expansion of irrigation through decisions about water prices from federal projects. The Forest Service has been involved in water development projects

by providing permits for locating dams, diversion and conveyance structures on national forests. When measures affecting demand are needed, states have played the lead role. Controlling water use and water rights are areas that have historically been state responsibilities. Demand management has traditionally focused on managing the queue of users, to assure that everyone gets the share to which they are entitled.

The Forest Service Mission in Easing Water Shortages

Vegetation management, weather modification, and construction of snow fencing all can help augment water yield from forests and rangeland. They have been proven feasible in studies on experimental watersheds and have been used on a limited scale on national forests in Colorado and California to support ski developments. The use to date also has demonstrated that expanding the use of these measures to the scale needed to increase supplies substantially and ease water shortages may create significant environmental and social impacts due to the cumulative effects of using the measures on a multi-state basis. In many cases, implementing these measures on the scale needed may be judged too costly.

Major water shortages are projected for the Lower Colorado water resource region and lesser shortages in the Upper Colorado, California, Great Basin, and Rio Grande water resource regions if recent water use trends continue. If they do, the Forest Service needs to consider the following questions:

— To what extent should the Forest Service adopt a policy of implementing vegetation management, weather modification, and/or snow fencing construction to help alleviate the shortages?

— How big a contribution should the Forest Service make toward easing water shortages using these measures and what does that imply for the intensity of application of the measures and the scope of geographic coverage?

— How quickly can or should the Forest Service proceed with implementation?

Concurrently with the Forest Service considering these questions, other government agencies also need to examine their role in easing the projected water shortages.

The Role of Other Government Agencies in Easing Water Shortages

The major non-price tool available for easing future water shortages is water conservation. Conservation has no widely-accepted definition. In this section, conservation means "use less water." In other reports, water conservation is defined as using the same amount of water more efficiently, such as growing more crops with the same volume of water. If crop shortages were the problem—and they are not—then defining water conservation as improving water use efficiency would help ease the shortage. Rather water shortages are the main concern. People in the five regions where shortages are projected are going to have to conserve—use less—water in the future than the

current trend in water use indicates. The question is, what can other government agencies do to help the residents conserve water.

Few parallels exist at the federal level where conservation practices have been successfully employed. The oil crisis of the early 1970s is the most recent example of major federal initiatives to promote conservation. A variety of tools were used, including setting energy efficiency standards for automobile and appliance manufacturers, giving income tax credits for home improvements that saved energy, and increasing the funding for mass transit and car-pooling. Although gasoline rationing coupons were printed, rationing was never imposed. One must go back to World War II for the last use of rationing as a way to enforce conservation of certain resources. It is hard to imagine how federally mandated conservation measures similar to those used during the oil crisis would be imposed for water, especially because the projected water shortages are not nationwide in scope.

State and local governments, on the other hand, have often taken the lead to promote conservation on a regional and local basis. Taxes have often been used to increase prices, thereby promoting conservation. Non-price methods have also been used. For example, during the oil shortage, gasoline station hours were regulated and 10 gallons was established as the maximum purchase in many areas. In some localities, vehicle license plate numbers were used to implement rationing--if the last digit on the plate was odd, you could only get gasoline on odd-numbered days of the month. Similar regulations have been used during temporary water shortages due to droughts. For example, car washes have been closed or their hours of operation restricted. Residences with odd-numbered addresses could only water lawns on odd-numbered days. Regulations like these already exist in many areas. To implement them, a designated elected official must usually issue a formal declaration that a water emergency exists. Then, the regulations go into effect for an indefinite period until the emergency has passed.

In contrast to these measures designed to deal with droughts on a temporary or seasonal basis, dealing with the projected water shortages will require more permanent measures. A long-term structural change is needed in the water use trend since 1960. The kinds of measures cited above deal with the symptom of the problem, not the root cause.

The Real Problem Is Water Prices

The water conservation measures employed so far deal with physical shortages. But physical shortages are only a symptom of the real problem in the five water resource regions. The real problem creating the water shortages is that water used for irrigation is under-valued in the marketplace. It is available at a lower, subsidized price than what it is really worth. Federal irrigation water development projects were originally designed to sell water at a price covering project costs. But federal government policy has kept prices low, so receipts for water sold are only covering a small portion of project costs. It is a well-known economic fact that items available free or below cost will get greater use compared to the quantity that would be used if fair market prices were charged. This is what has happened with irrigation water usage. Water priced below its value in production is the major reason why irrigation

comprises 80 percent of water consumption and why shortages are projected in these five regions.

Institutional barriers also have been erected that prevent a market for water from emerging; or where one has emerged, constraints have been imposed that keep the market from functioning efficiently. The barriers and constraints typically hinder the sale of water and water rights to non-agricultural users willing to pay the fair market price for the water. For example, in some western states, water rights cannot be separated from the real estate where they are used for irrigation. Thus, municipalities that need water to meet the needs of expanding populations and diversifying economies are forced to buy farm real estate, for which they have little use, to obtain the rights to the water needed.

Recent Gains in Productivity Decrease Reliance on Irrigation

A century ago, the federal and state governments embarked, with good intentions, on the path of using agriculture to drive development of the West. The burgeoning population of the U.S. needed agricultural products; railroads were becoming available to deliver crops to distant eastern markets; and irrigation was the technology available in the early 1900s to improve crop productivity and meet society's needs. A stimulus to spread development quickly over a wide area was needed. Water development projects provided it. Today, irrigation is used on over 60 million acres, but its use appears to have peaked. Nearly 2 million acres have been taken out of irrigation since 1980. In some parts of the southern Great Plains and Rocky Mountains, it has become too costly to pump groundwater for irrigation. Net returns from dryland farming equal, and often exceed, net returns from irrigated production in those areas.

Future gains in crop productivity will come more from advances in genetics and biotechnology than from increasing irrigation. For example, new crop varieties have been developed for dryland farming in semi-arid areas and for saline soils. The <u>RCA Appraisal</u> (Department of Agriculture 1987) projects continued increases in agricultural productivity from genetics and biotechnology out to 2030. These new ways of boosting productivity can be combined with irrigation to meet society's crop needs and on fewer acres. They can also be used as substitutes for irrigation. The gains from these new methods are the underlying reason why the <u>Appraisal</u> projection of the agricultural acreage required to meet society's needs in 2030 is 160 million acres less than today and irrigated acreage is 19 million acres--one-third--less than today.

Farmers will be able to keep yields and farm income steady using the new methods, but they will change their farming and irrigation practices. The changes will affect both farmers and the farm economy because of the farm capital invested in irrigation (e.g. equipment and field leveling), the reduction in sales of other products associated with irrigation (e.g. fertilizer usage is much higher when irrigating), and the potential change in asset value of the irrigation rights held. Although in theory, farmers should not allow sunk costs in capital to stand in the way of changing to a more efficient operation, that is easier said than done. More important, many state water rights laws contain provisions that water must be used or the rights to

it will be lost and that water rights cannot be sold without selling the land formerly irrigated. Such provisions make a decision to abandon irrigation very difficult because either the farm size must be reduced or a valuable asset--the water right--will be lost without compensation.

As new methods of improving agricultural productivity are implemented and the recent trend in increasing the acreage irrigated drops, the potential will emerge to make a major structural change in recent water use trends in the five water short regions. The structural change could reduce the likelihood that shortages will emerge. As pointed out in Chapter 4, if irrigation water usage can be held at 1985 levels, the shortages disappear in the Rio Grande, Upper Colorado, and Great Basins. In California, holding irrigation water use at 1985 levels reduces the deficit enough that conservation in other uses will remedy the problem. The major impact of freezing irrigation water usage at current levels is that irrigation will no longer be the primary engine of growth for the agricultural economy in these regions; rather it will become a constraint. In the Lower Colorado basin, holding irrigation water usage at 1985 levels will not eliminate most of the shortage.

Freer Water Markets Will Help Reduce Projected Shortages

What, then, is the most efficient way of holding irrigation water usage at current levels in the Rio Grande, Upper Colorado, Great Basin, and California regions and of reducing irrigation water usage in the Lower Colorado region? The nation's economic system is predicated on allowing the market to function and induce changes in resource allocations. So seeking a market solution should be the first priority. Because irrigation water is the lowest-valued off-stream water use, a freely-functioning, reasonably competitive, market should help water move from irrigation to higher-valued off-stream uses. It is too early to determine if switching to fair market pricing for water and lifting market constraints will be sufficient government intervention to ease projected shortages in the former four regions. Switching to fair market pricing will probably not induce sufficient change in irrigation water usage in the Lower Colorado region to eliminate the projected shortage. There, widespread, strong water conservation measures may also be necessary.

Without changes in current water pricing and institutional arrangements, the projected shortages will most likely occur. Current institutional frameworks that tie water rights to real estate and that mandate using water or losing the right to it provide the farmer with few options and little flexibility. These frameworks are protectionist and designed to stimulate expansion in demand--the opposite of what is needed to ease shortages. The current crop-surplus situation and Appraisal acreage projections hardly merit further expansion of crop production on the basis of economics. Non-price actions can be taken to help avoid the shortages, but their effect will be to further constrain free market functioning. Farmers need flexibility to respond to clear market signals for crops and water in ways that best fit their short- and long-term operations. Being able to buy and sell water in competitive markets could provide the additional flexibility needed. For example, being able to sell water rights separate from land may enable some farmers to liquify one of their farm's major assets, yet still remain a viable farm enterprise using new varieties better suited to semi-arid, dryland farming. To help free up the

markets for water, state and federal agencies need to consider the following policy issues:

— Should water markets be decontrolled to ease projected water shortages? Should water rights be decoupled from real estate so water and land can be sold separately?

— How far should water prices be allowed to rise and what will be the remaining imbalance between demand and supply at that price level? Can non-price actions be taken to close the remaining gap? What will the impacts be of alternative courses of action on current and potential future water users?

— To what extent should cross-compliance measures be used to promote water conservation? Should crop subsidy payments be made on crops grown with subsidized water? Should receipt of crop subsidy payments be tied to having an approved water conservation plan?

Social Preferences for Water Use Are Changing

The major impetus for easing water shortages is to assure that sufficient water exists to meet society's needs. Historically, the first approach often tried in such situations was to increase supplies--increase water yields--rather than face the reality that resources may be limited. Some water interests may still advocate such an approach through modification of vegetation, redistribution of high mountain snowpack, and weather modification. All these approaches are attempts to retain the established water use structures and institutions. However, as society and the economy have become more urbanized, the voting population has become progressively less sensitive to agricultural issues and concerns. Urban/suburban voters are demonstrating concern about the environment in terms more relevant to their lifestyles--they want fish and wildlife populations and recreation opportunities preserved. Consequently, if water shortages become more prevalent and they affect urban/suburban lifestyles in terms of having less water-based recreation and fewer places to go fishing because in-stream habitat is poor, political support will grow at the state level for changing the doctrine of prior appropriation to give more weight to priority of beneficial uses, <u>from a non-agricultural perspective</u>. The question no longer is <u>will</u> the shift in water rights emphasis occur, the questions are <u>when</u> and <u>how fast</u> will it occur. Government programs to ease shortages that seek to perpetuate the status quo of appropriations priorities will increasingly come in conflict with social preferences. The trend in voter preferences suggests that suburban/urban interests will eventually force a change in water use priorities. The effect will be that irrigation will probably cease to enjoy its current priority in use of water. Evidence of this change is already being observed as water rights are purchased for non-agricultural uses and as in-stream uses are recognized in courts.

Reversing the Trends in Wetlands Losses

The federal government has passed a number of laws over the past 50 years to encourage wetlands preservation. The Migratory Bird Hunting and Conservation Stamp program has provided millions of dollars for wetlands conservation.

Other incentive programs have also been passed. But the latest wetlands census indicates these programs have been unable to stem the tide; 300,000 acres of wetlands continue to be lost annually. The Food Security Act's swampbuster provision is another example. But if someone not engaged in agriculture wants to convert wetlands to a non-agricultural use, the provision will not deter the conversion. To reverse the trend in wetlands losses, incentive programs need to be strengthened. Plainly put, more money would need to be made available to conserve wetlands--a difficult task given the nation's current fiscal situation. But a step that will not cost the government money is to change the income tax provisions encouraging wetlands conversion, outlined in Chapter 7.

States and local governments also can do more. Many local property tax administration policies contribute to wetlands conversions. In other jurisdictions, policies have begun to change. For example, "current use" valuation provisions are used in some areas to protect encourage continuation of certain land uses, such as forestry or crop production. Current use provisions do not assess land value based upon the highest-and-best use of the land; rather, the assessed value is based upon the current use of the land. So long as landowners engage in forest management, for example, they retain the assessed value of forest land, in spite of the potential use of the land for some higher-valued purpose. Similar provisions are being enacted for farmland near rapidly growing urban areas. If current-use valuation provisions were extended to wetlands--many generate less income per acre than cropland--this would have a significant effect upon reversing the trend in wetlands losses.

Question 2: What should be the mission of the national forests in the production of water and other watershed resources?

The discussion about question 1 has already highlighted policy issues about water yield augmentation.

Because 80 percent of the water in the West emanates from national forests, the Forest Service will continue to play a role in the diversion, storage, and development of water resources. These objectives will probably be emphasized in the future to a greater extent in the remainder of this century than augmenting water yields from forest land.

Maintaining and Improving Water Quality Will Become Top Priority

There will be increasing concern about the Forest Service's ability to maintain high-quality water in streams originating in and passing through national forests. As concerns mount about the skyrocketing costs of removing pollutants emphasis will increasingly be placed upon keeping these items out of the water. Controlling sediment, the biggest nonpoint-source pollution threat from silvicultural and range management activities, will be a high priority. Implementing BMPs is the conventional approach to controlling erosion and protecting water quality. The Federal Facilities Compliance Program is placing renewed emphasis on cleaning up point- and nonpoint-source pollution from federal facilities. Rehabilitation and restoration of eroding watersheds is a major concern. The fate of chemicals--fertilizers and pesticides--applied to forests and rangelands is also a concern.

A shift in ownership of senior water rights is already underway in the West. In many states, especially those where shortages are likely to emerge, municipalities are acquiring more senior rights from irrigators. Municipalities prefer to pay the costs of diverting and transporting clean water rather than paying the cost of treating water to render it potable. Once the senior rights are secured, the municipalities will become vocal proponents of maintaining water quality at high levels. Thus, local governments are going to play an increasingly prominent role in reviewing land management decisions for their water quality impacts. Further, these local governments may be located some distance from the national forest, and so working relationships may need to be built where close ties have not existed in the past.

Ensuring Suitable In-stream Flows Is An Emerging Need

Ensuring suitable in-stream flows for fish and wildlife habitat and for recreation has emerged as an issue, and will become increasingly important in the coming decades. The shift in social priorities for water use will elevate concern about in-stream flows.

Serving in-stream flow needs will require close cooperation with state agencies, including water development, natural resources, fish, and wildlife agencies. New memoranda of understanding may be needed to formalize cooperation. Partnerships with interest groups could be explored as a way of solidifying support in a tangible way for ensuring suitable flows. Securing interest group participation in building and maintaining fish habitat improvements is one example of the kinds of help they can provide.

Managing Riparian Areas Will Become Increasingly Important

Riparian areas are at the interface between land areas and streams. Consequently, they represent the last line of defense against sediment and other pollutants reaching the streams and also play a significant role in providing habitat for fish and wildlife and in regulating runoff rates. The demands placed upon riparian areas to help reduce nonpoint-source pollution will gain importance in the coming decades. Their use in regulating runoff also helps mitigate damages from minor flood events. Management of riparian areas will become even more intensive.

Integrated resource management will become more important over time. Watershed condition information will play an important role in bringing integrated resource management into broader use. Riparian areas will be where integrated resource management is practiced most intensively; for many national forests, riparian areas are also where it will be practiced initially.

Long-term Monitoring and Evaluation Sites Should Be Established

One of the most important tools for solving complex ecological problems, such as determining the effect of acid deposition and ozone on forests and rangelands, is having long-term trend data available. An important component of collecting long-term trend information is identifying sensitive areas and begin measurements needed to understand ecosystem functioning. Without

background information on how the ecosystem functioned before being polluted, it is very difficult to determine the true effect of the pollutants after they begin to influence the ecosystems.

The most important obstacle to be overcome in establishing long-term monitoring and evaluation sites is that it takes many years for the payoff to come. During the time when the essential baseline data is being collected and costs are being incurred while benefits are still some years away, it is often tempting to postpone or cancel data collection, especially when budgets tighten. This may be viewed as wise budgeting, but it could have a very large social cost--the data may lose its ability to contribute toward solving major environmental problems. The Forest Service makes periodic investments its human resource by providing training and a variety of assignments to prepare employees for progressively more challenging assignments. Making investments in beginning long-term data records now can also help prepare for solving more challenging questions in the future.

Establishing long-term monitoring and evaluation sites is by no means only a research task. National forest managers need information on long-term trends in ecological change to provide feedback into planning programs. Long-term trend data such as this is essential for constructing a feedback loop for managers; pointing out how they can learn from their decisions and experience. Long-term trend information will also make possible the evaluation of cumulative effects over time. To make these kinds of analyses possible, planning for monitoring programs should be sensitive to two key elements: managers should decide on a specific objective(s) for the monitoring process; and a statistically valid experimental design should be planned that responds to the objective(s). Only then will the long-term data collected be helpful in maintaining a quality environment.

Because of their relative isolation from urban areas, parts of national forests are often the only places left untouched by some of the pollutants affecting more developed and more populated areas. Wildernesses are important because they provide places where baseline water quality information can be collected, but other places on the national forests are important too. It is often the places outside formally designated wilderness where vegetation management occurs that can provide the most important long-term data on environmental effects of management activities on watersheds and water quality. A long-term monitoring and evaluation programs for water quality and watershed health would provide improved management information for all land ownerships.

Question 3: Should policies for management of national forest watersheds vary among Regions?

The key objectives of national forest management--maintaining water quality; ensuring suitable flows in streams for fish, wildlife, and recreation; managing riparian areas; augmenting water yields--require consistent nationwide policies. But the targets and levels attained for each objective are likely to differ considerably among Regions, even though each is complying with the same policies.

The differences in water uses and water rights institutions between the East and the West are difference that would justify different policies among Regions. In the economic arena, conditions for optimality are often a function of prevailing institutional arrangements.
What is most efficient under one scenario may be infeasible under a different scenario. In such cases, leaders do well to specify policies in general terms that span any differences in institutional frameworks, and let implementation arrangements work out the differences among institutions.

Consequently, policies need to be specified that are consistent nationwide, yet allow Regions sufficient flexibility in developing regional objectives and implementation arrangements to deal with local institutions. For example, fish and wildlife species differ among Regions. Black bass in Region 8 have different needs than salmon in Region 6. Consequently, practices employed to secure suitable minimum flows and the flow levels themselves will differ between the Regions. Yet both can adhere to a consistent national policy about promoting habitat and managing riparian areas. Regions are the key organizational level for translating national policies and objectives into objectives tailored to regional situations and institutions.

The concept of cumulative effects is becoming more important in national forest management. The idea is that while some effects may be innocuous in a local basis or for an isolated project, when the sum of all these effects are considered on a regional or national basis, the total is unacceptably high. For watershed managers, nonpoint-source pollution is an item whose cumulative effects have become very important. Regions could play the lead role in establishing the tolerable level of cumulative effects for sediment generation and then monitor the situations on national forests to assure that the cumulative effect is within limits.

Question 4: What should be the place of multiple-use as it relates to water and watershed management on national forests?

Multiple-use is an important concept for watershed management, even though the term itself has become politicized in recent years. The importance of multiple-use from a watershed standpoint has to do with the historical approach water supply firms and municipalities have taken to watershed management. The historical approach is to declare water supply watersheds off limits for public use and most vegetation management practices. If the public is kept out and the vegetation remains undisturbed, then water quality will remain high and risk of contamination (and associated treatment costs) will be low. This approach to obtaining potable supplies from watersheds stems from the turn of the century before chlorination and filtration were used. Because the mechanism of contamination was understood but how to clean up contaminated water was not, preventing contamination was stressed. Although municipal supplies are routinely disinfected today, some organisms, such as giardia bacteria, are remarkably resistent to chlorination and so preventing contamination remains a public health challenge.

As senior water rights are acquired by municipalities, this historical approach will be urged on public land managers as a way of guaranteeing high quality

water supplies. For example, the management guidelines are more restrictive for the watershed where Boulder, Colorado obtains its supplies than the management guidelines for the nearby Indian Peaks Wilderness.

It is very important for the Forest Service to demonstrate that other resources in watersheds can be managed while still maintaining high-quality water. Areas where management activities, such as recreation, grazing or timber harvesting, pose high risks to water quality need to be delineated. Unless greater sensitivity is demonstrated to integrating resource management in ways that protect pristine water supplies, management options will become increasingly constrained as municipalities acquire larger numbers of senior water rights. If this happens, multiple use will become an anachronism for watershed managers.

Question 5: What is the Forest Service mission in the production of water and other watershed resources on nonindustrial private lands?

There are three ways that the Forest Service can provide assistance in the production of water and related watershed resources on nonindustrial private lands: improving water quality, restoring and protecting riparian habitat, and helping to reduce flood damages.[1] All three kinds of assistance will lead to improvements in watershed conditions.

Private Landowners Need Assistance to Improve Water Quality

Private forests are key lands in the fight to reduce nonpoint-source pollution. Chapter 7 pointed out that lack of financial incentives and lack of knowledge were two major obstacles to private landowners using BMPs for control of pollution. That chapter also pointed out that BMPs are often not in the financial interest of landowners and that BMPs for silvicultural activities are generally known.

Financial assistance programs are currently in place. They are, however, inadequate to meet the needs of nonpoint-source pollution control. Cleaning up nonpoint-source pollution has emerged as a larger, more difficult, and more costly task than imagined when the Clean Water Act was passed. Additional funds could be provided for the forestry portion of the Agricultural Conservation Program (ACP) and for water quality aspects of timber production under the Forestry Incentives Program (FIP). More funding is needed under both programs to attract wider participation by landowners. More money per landowner is also needed to cover the additional expenses of BMPs. More assistance is needed to make landowners aware of the reforestation income tax credit and how they can use that provision to help pay for BMPS that are part of their site preparation and planting activities.

Not only is financial and technical assistance needed to employ BMPs as part of current timber harvesting and regeneration activities, but assistance is also needed to restore and rehabilitate areas abused in the past. For example, strip mines worked in the early part of this century and which have been abandoned for years, are still emitting sediment and other kinds of pollution. Research has demonstrated that planting abandoned strip mines to mixtures of

trees and legumes is an effective way to rehabilitate the land, rebuild soil productivity, reduce nonpoint-source pollution, and collectively restore productive watershed conditions. Assistance is needed to help cure problems created by past land uses.

Technical assistance is also needed for landowners switching from agricultural to forestry or range management to reduce agricultural nonpoint-source pollution. The Conservation Reserve Program is providing the impetus for farmers with erodible land to switch from growing agricultural crops to planting trees or grass. In return for keeping the land in trees or grass for a decade, the landowner receives annual payments from the Department of Agriculture. Landowners need help weighing the merits of removing erodible land from crop production and in choosing between trees and grass as permanent cover. While receiving Conservation Reserve payments, the landowner cannot cut timber or harvest forage from these lands. The landowner can, however, lease the land for hunting. So in addition to providing technical assistance about timber production, assistance could be provided on how to increase wildlife populations and thereby hunting lease rates. The more income landowners can obtain from not growing crops, the lower the incentive to convert it back to agriculture and the lower the likelihood that it will contribute to erosion problems in the future.

Private Landowners Need Assistance to Restore and Protect Riparian Areas

Many private landowners are unaware of the importance of riparian areas in preventing nonpoint-source pollution, reducing flood flows, and maintaining productive watershed conditions. Additional support is needed for using BMPs and the Conservation Reserve Program to establish streamside management zones on private lands. Information and education programs are needed that provide management information on how to integrate resource management and the benefits of doing so.

Private Landowners Need Assistance to Reduce Downstream Flood Damages

Watershed rehabilitation efforts on private lands can increase the rainfall infiltration rates and moisture-holding capacity of soils, thereby improving watershed condition. Both actions help retard runoff. If runoff comes more slowly, the peak flows are reduced and water moving at lower velocity carries less sediment off the site. Trees are especially effective in promoting infiltration and slowing runoff.

Fire protection assistance is needed to help keep vegetation growing on important watersheds. What determines watershed importance is often the magnitude of off-site damages that sediments and flood water would cause if the vegetation on the watershed were destroyed. The proliferation of dwellings on headwater flood plains is raising the amount of damage likely to occur from flooding as well as from fire. So maintaining vegetation on watersheds that would otherwise have rapid runoff becomes an important part of flood damage reduction efforts. Fire is often the most likely reason why vegetation on such watersheds would be destroyed. If fires do occur, the emergency watershed program can provide assistance for quick revegetation of burned areas.

Reversing the trend in wetlands conversions is also an important part of reducing flood damages. Wetlands provide temporary storage of flood water and slow down flood water velocity. Preventing the conversion of wetlands is the major reason for the swampbuster provision of the Food Security Act of 1985. Many of the wetlands thus saved are bottomland hardwood stands. The impetus for conversion is often inability to obtain income from wetlands. So technical and financial assistance is needed so that landowners can earn some returns from not converting wetlands to other uses. Technical assistance is needed to help manage bottomland hardwood tree species for timber. But assistance on how to obtain returns from other wetlands resources, such as wildlife, through other means, such as hunting leases, can also be used to help maintain wetlands so they will be available to help reduce downstream flood damages.

Question 6: What is the mission of Forest Service research programs in the production of new information and technology needed for watershed and water quality management?

The implications, opportunities, and obstacles outlined in this report identify two interrelated missions for Forest Service research on watershed and water quality management: cumulative effects and site productivity.

Cumulative Effects, Analyses Today and In the Future

Cumulative effects, already addressed under question 2, are an important research area for the Forest Service. Small disturbances scattered across a watershed in space and in time may appear innocuous alone, yet their cumulative effect on downstream water uses may be substantial.

Disturbances scattered spatially across a watershed are important. For example, small timber harvest areas scattered through a watershed each produce some sediment. They may be so well scattered that they are objectionable neither on visual grounds nor in terms of the sediment generated at each harvesting location. The road network that connects them, however, may have a bigger effect upon the cumulative erosion in the watershed than all the harvest sites put together.

Disturbances may also result from events scattered through time. Uneven-aged timber management is often advocated as less offensive, visually, than clearcutting. But from a sediment generation perspective, coming into a stand every 5 to 10 years to cut and skid out a few trees may, over time, generate more sediment and larger cumulative effects than a major thinning, clearcut, and artificial regeneration will create from an even-aged stand. For example, continual small harvests can keep just enough sediment in the stream to cause lower respiration and reproduction rates in fish, leading to less vigorous and lower numbers of fish for a longer time than two or three site entries over a rotation.

Research is needed into sediment generation and transport mechanisms and differences in rates from different land management activities and their cumulative effects upon water quality and aquatic organisms. This information is essential to developing and testing new BMPs and technology to improve

existing BMPs. One of the major needs is to find a way to keep erosion under control on slopes after roads are constructed across them. Improving revegetation of exposed road cuts and fills with native vegetation is important. When the sites disturbed at located in difficult settings, such as at high elevations or in semi-arid areas, native plants often grow slowly and take many years to revegetate an area. Asexual propagation of alpine species at lower elevations for revegetation purposes has not been extensively studied. Because high-elevation watersheds will become most critical for water supply purposes, research with species common at high elevations will grow more important.

In addition to work on sediment, the cumulative effects of acid deposition and chemical buildups in watersheds also need to be explored. Today, just barely enough long-term background data exists to begin evaluating the temporal variability in rainfall constituents. The system of monitoring stations numbers nearly 200, but the length of records is just a decade old. Differences exist within the scientific community over the roles of acids versus ozone in forest growth declines and chemistry of streams and lakes. Some of the differences may arise from the variability in rainfall constituents by season and by geographic location. Cooperative work with scientists at other government laboratories and at universities here and abroad should continue.

Chemical buildups in watersheds are also an issue of emerging importance. Nutrient and energy cycling are related to soil and site productivity. The fate of pesticides and fertilizers applied to promote vegetation growth must be more fully explored. Differences in rates of movement within the ecosystem need to be studied, both as they relate to the composition of the chemical, as well as the transportability of the chemical. For example, differences to consider include: is the chemical persistent or does it break down rapidly; if it breaks down, are the decomposed products more or less mobile and more or less harmful, than the original chemical; does the chemical adsorb readily and tightly to soil colloids and does this affect its activity; if it does adsorb tightly to soil, what effects will it have on aquatic ecosystems if the soil erodes and it winds up in a stream. Many of these same questions have been asked of agricultural chemicals recently; many of the chemicals are the same as ones applied to forests. Their role in silvicultural nonpoint-source pollution must be explored. Again, the short time series of data available hinders providing quick answers to these kinds of questions.

Only now when confronted with complex problems such as acid deposition and chemical buildups in watersheds is the value of long-term records becoming understood. Thus, the value of research locations such as Hubbard Brook Experimental Forest, New Hampshire; Fraser Experimental Forest, Colorado; Coweeta Hydrologic Laboratory, North Carolina (50 years old); Crossett Experimental Forest, Arkansas (60 years old); and the Wind River Experimental Forest, Wyoming (70 years old) is better understood today. Today, the Forest Service maintains 84 experimental forests across the nation. There have been 113 experimental forests at one point or another this century. Sixteen were lost in the 1960s. If long-term records, such as those available on the 84 experimental forests, are allowed to lapse, society may lose the capability to answer difficult and complex problems in the future.

The final cumulative effect in need of research is defining the in-stream flows necessary to support different in-stream water uses under different situations. Each water withdrawal affects the volume of water in a stream and the suitability of the stream for fish and wildlife habitat and recreation. Considered alone, most proposed withdrawals or diversions are not large enough to cause significant impacts on suitability of in-stream flows. But when a proposal is considered in light of the cumulative effect of all withdrawals and diversions, the effects of an additional permit to withdraw or divert water may be substantial. Land managers and owners are frequently asked to make judgments about the levels of in-stream flows that need to be maintained to avoid detrimental effects on in-stream water uses. Little information is available to guide their decisions. Research to develop procedures for quantifying and evaluating the cumulative effects of withdrawals and diversions could be most helpful in the long-term. Developing initial estimates of the suitable flows needed under certain conditions could be most helpful in the short-term.

Maintaining Land Productivity Is An Important Part of Watershed Research

Maintaining land productivity was mandated by the National Forest Management Act of 1976. The Forest Service's research mission could focus on land, or more precisely, soil productivity to help fulfill agency obligations under that act.

The objective of soil productivity research is to develop an ability to use site characteristics to predict the productivity of a site for a variety of resources. Work has been underway for some time to predict timber outputs from site characteristics. One of the major avenues of work is to define the nutritional needs of major commercial timber species. So far, loblolly pine is the species about which the most is known. But much still is not known about loblolly; even less is known about other commercial species.

The relationships between soil productivity and agricultural crops are much better known than the relationships between soil productivity and trees. Some results are available for forage from agricultural research too. Interdisciplinary teams have been responsible for many of the advances in the agricultural field, particularly in plant breeding and seed development. A similar interdisciplinary approach may prove useful for soil productivity research in forested ecosystems. An interdisciplinary team, having skills in the areas of genetics, silviculture, soil science, and ecological modeling, could take advantage of the synergy among specialties. Not only do models have to be constructed, but ways need to be developed to validate them--which may be even more difficult that building them in the first place. At present, there is no practical way to evaluate the reliability of outputs from models, even when the separate reliabilities of their inputs are known.

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Department of Agriculture. 1987. The second RCA Appraisal--soil, water, and related resources on non-federal lands in the United States: Analysis of conditions and trends. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service.

Notes

1. Providing technical and financial assistance to nonindustrial private forest landowners has been a Forest Service responsibility for many years. Providing assistance to rangeland owners is an SCS responsibility.

Appendix A

DEMAND STATISTICS FOR WATER: 1960-2040

Tables A.1 to A.6 summarize freshwater withdrawals by use. Each table shows the amount of water withdrawn by water source (groundwater, surface water, and wastewater, where applicable) by water resource region. Water resource regions were defined by the Water Resources Council, figure A.1. They divided the continental U.S. into 17 major hydrologic basins. Data is also shown for Alaska, Hawaii, and the Caribbean.

Tables A.7 to A.12 summarize freshwater withdrawals by use and water source, but present the information by Forest Service Region. Administration of the National Forest System is decentralized by 9 Regions, figure A.2. Water withdrawal and consumption information by State were obtained from U.S.G.S. The States were then combined into Forest Service Regions. For purposes of display, Forest Service Regions have been further aggregated into 4 geographic regions--North, South, Rocky Mountains, and Pacific Coast. The North is the Eastern Region. The South is the Southern Region, including Puerto Rico and the Virgin Islands. The Rocky Mountains contain the Northern, Rocky Mountain, Southwester, and Intermountain Regions. The Pacific Coast contains the California (including Hawaii), Pacific Northwest, and Alaskan Regions. In general, Region refers to Forest Service Region, while region refers to some other geographic area, defined by the context of the discussion. Exceptions will be explicitly noted.

Tables A.13 to A.18 summarize consumption by use for Forest Service Regions and water resource regions. Consumption data is not available by water source.

Figures A.3-A.16 illustrate the trends in withdrawals by water use category and by source--groundwater versus surface water.

Table A.1--Freshwater withdrawals for thermoelectric steam cooling use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day)

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	6	0	1	1	1	0	0	0	0	0	0
Mid-Atlantic	3	8	100	170	110	44	60	59	59	58	58
South Atlantic-Gulf	17	17	32	91	88	35	33	33	33	32	32
Great Lakes	0	0	38	64	30	12	21	21	20	20	20
Ohio	19	40	54	32	52	21	22	22	21	21	21
Tennessee	0	0	0	0	0	0	0	0	0	0	0
Upper Mississippi	7	9	290	34	13	5	53	53	52	52	51
Lower Mississippi	21	76	66	27	54	21	23	23	23	22	22
Souris-Red-Rainy	3	1	1	0	1	0	0	0	0	0	0
Missouri Basin	5	61	310	310	48	19	106	104	103	102	102
Arkansas-White-Red	37	42	46	56	70	28	27	27	27	26	26
Texas-Gulf	301	320	51	32	30	12	18	18	17	17	17
Rio Grande	179	190	15	22	15	6	8	8	8	8	8
Upper Colorado	0	0	0	0	0	0	0	0	0	0	0
Lower Colorado	18	19	44	38	45	18	20	20	20	19	19
Great Basin	0	0	4	4	5	2	2	2	2	2	2
Pacific Northwest	0	0	0	7	5	2	2	2	2	2	2
California	290	300	300	380	890	352	248	245	242	240	239
Alaska	0	1	1	2	8	3	2	2	2	2	2
Hawaii	14	31	82	140	130	51	56	55	54	54	54
Caribbean	0	0	0	0	3	1	0	0	0	0	0
Total Groundwater	920	1115	1435	1410	1598	633	703	694	686	679	676

Table A.1--Freshwater withdrawals for thermoelectric steam cooling use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Surface Water											
New England	620	870	1900	1900	2300	2041	2456	2734	3012	3289	3567
Mid-Atlantic	8100	10300	15000	14000	15000	13312	16019	17830	19641	21452	23262
South Atlantic-Gulf	8400	10900	15000	18000	19000	16861	20291	22585	24879	27173	29466
Great Lakes	17500	20000	26000	25000	27000	23961	28835	32095	35354	38614	41872
Ohio	16000	20000	27000	27000	30000	26623	32039	35661	39283	42904	46525
Tennessee	5600	5900	6100	8700	9300	8253	9932	11055	12178	13300	14423
Upper Mississippi	8200	13000	12000	13000	16000	14199	17087	19019	20951	22882	24813
Lower Mississippi	930	1800	4000	6000	7700	6833	8223	9153	10083	11012	11941
Souris-Red-Rainy	0	64	140	190	53	47	57	63	69	76	82
Missouri Basin	2200	2200	3000	3900	8100	7188	8650	9628	10606	11584	12562
Arkansas-White-Red	3130	1700	1900	2800	9900	8786	10573	11768	12963	14158	15353
Texas-Gulf	1877	2600	4700	7600	950	843	1015	1129	1244	1359	1473
Rio Grande	123	170	6	5	2	2	2	2	3	3	3
Upper Colorado	118	120	100	160	140	124	150	166	183	200	217
Lower Colorado	2	2	3	110	45	40	48	53	59	64	70
Great Basin	76	170	130	78	120	106	128	143	157	172	186
Pacific Northwest	7	5	26	29	23	20	25	27	30	33	36
California	140	660	1200	1100	1100	976	1175	1308	1440	1573	1706
Alaska	86	1	68	18	22	20	23	26	29	31	34
Hawaii	12	41	46	32	9	8	10	11	12	13	14
Caribbean	4	0	0	0	0	0	0	0	0	0	0
Total Surface Water	73125	90503	118319	129622	146764	130243	156738	174457	192176	209893	227606

Table A.1--Freshwater withdrawals for thermoelectric steam cooling use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Total Withdrawals											
New England	626	870	1901	1901	2301	2030	2442	2716	2991	3266	3541
Mid-Atlantic	8103	10308	15100	14170	15110	13329	16035	17838	19642	21446	23249
South Atlantic-Gulf	8417	10917	15032	18091	19088	16838	20256	22535	24813	27092	29370
Great Lakes	17500	20000	26038	25064	27030	23844	28684	31911	35137	38364	41591
Ohio	16019	20040	27054	27032	30052	26510	31891	35478	39066	42653	46240
Tennessee	5600	5900	6100	8700	9300	8204	9869	10979	12089	13200	14310
Upper Mississippi	8207	13009	12290	13034	16013	14126	16993	18904	20816	22727	24639
Lower Mississippi	951	1876	4066	6027	7754	6840	8229	9154	10080	11005	11931
Souris-Red-Rainy	3	65	141	190	54	48	57	64	70	77	83
Missouri Basin	2205	2261	3310	4210	8148	7188	8647	9619	10592	11565	12537
Arkansas-White-Red	3167	1742	1946	2856	9970	8795	10580	11770	12960	14151	15341
Texas-Gulf	2208	2920	4751	7632	980	864	1040	1157	1274	1391	1508
Rio Grande	272	360	21	27	17	15	18	20	22	24	26
Upper Colorado	117	120	100	160	140	123	149	165	182	199	215
Lower Colorado	21	21	47	148	90	79	96	106	117	128	138
Great Basin	76	170	134	82	125	110	133	148	162	177	192
Pacific Northwest	7	5	26	36	28	25	30	33	36	40	43
California	430	960	1500	1480	1990	1755	2112	2349	2587	2824	3062
Alaska	86	2	69	20	30	26	32	35	39	43	46
Hawaii	26	72	128	172	139	123	148	164	181	197	214
Caribbean	4	0	0	0	3	3	3	4	4	4	5
Total Withdrawals	74045	91618	119754	131032	148362	130876	157441	175151	192862	210572	228282

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.2--Freshwater withdrawals for irrigation use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day)

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
<u>Groundwater</u>											
New England	0	10	20	12	8	6	6	6	7	7	7
Mid-Atlantic	48	82	77	150	97	74	73	76	80	82	84
South Atlantic-Gulf	322	1200	1300	1300	2000	1520	1501	1576	1645	1692	1733
Great Lakes	15	24	37	44	180	137	135	142	148	152	156
Ohio	3	6	8	10	88	67	66	69	72	74	76
Tennessee	2	1	2	2	3	2	2	2	2	3	3
Upper Mississippi	27	60	69	100	350	266	263	276	288	296	303
Lower Mississippi	590	1100	2000	3300	4800	3649	3602	3782	3947	4061	4159
Souris-Red-Rainy	0	2	8	26	46	35	35	36	38	39	40
Missouri Basin	2226	2700	4500	8800	11000	8362	8256	8667	9046	9306	9532
Arkansas-White-Red	2260	8000	5900	7900	8400	6386	6304	6619	6908	7107	7279
Texas-Gulf	6346	5800	5000	6000	3900	2965	2927	3073	3207	3300	3380
Rio Grande	2954	2700	2000	1900	1600	1216	1201	1261	1316	1354	1386
Upper Colorado	11	14	53	60	81	62	61	64	67	69	70
Lower Colorado	3189	4000	3900	4400	3900	2965	2927	3073	3207	3300	3380
Great Basin	760	890	760	1000	1000	760	751	788	822	846	867
Pacific Northwest	2900	3300	3000	4500	5100	3877	3828	4019	4194	4315	4419
California	8200	11000	16000	17000	18000	13684	13509	14183	14802	15229	15598
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	380	590	550	430	460	350	345	362	378	389	399
Caribbean	170	93	67	140	140	106	105	110	115	118	121
Total Groundwater	30403	41572	45251	57074	61153	56292	55575	58347	60894	62649	64167

Table A.2--Freshwater withdrawals for irrigation use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Surface Water											
New England	10	16	60	45	45	46	46	49	53	55	58
Mid-Atlantic	33	40	50	84	150	152	154	165	176	185	193
South Atlantic-Gulf	476	2000	1100	1700	1800	1824	1842	1977	2108	2216	2320
Great Lakes	31	41	53	56	120	122	123	132	141	148	155
Ohio	9	18	27	24	60	61	61	66	70	74	77
Tennessee	12	7	4	5	4	4	4	4	5	5	5
Upper Mississippi	16	25	35	42	29	29	30	32	34	36	37
Lower Mississippi	260	860	1200	1600	2900	2939	2968	3185	3396	3571	3737
Souris-Red-Rainy	13	23	4	16	18	18	18	20	21	22	23
Missouri Basin	11019	13000	14000	20000	18000	18240	18424	19767	21081	22163	23198
Arkansas-White-Red	2340	2200	2300	2100	2400	2432	2457	2636	2811	2955	3093
Texas-Gulf	806	1300	1100	1000	1600	1621	1638	1757	1874	1970	2062
Rio Grande	2294	3700	3500	2900	2700	2736	2764	2965	3162	3324	3480
Upper Colorado	5948	6400	7800	3700	7400	7499	7574	8126	8667	9112	9537
Lower Colorado	1952	2100	2600	3100	3700	3749	3787	4063	4333	4556	4768
Great Basin	4400	3900	5100	5000	4900	4965	5016	5381	5739	6033	6315
Pacific Northwest	16000	23000	24000	24000	24000	24320	24566	26356	28109	29551	30930
California	7800	15000	18000	19000	20000	20266	20472	21963	23424	24626	25775
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	540	570	680	520	450	456	461	494	527	554	580
Caribbean	110	160	73	120	180	182	184	198	211	222	232
Total Surface Water	54069	74360	81686	85012	90456	85767	86635	92947	99129	104215	109080

Table A.2--Freshwater withdrawals for irrigation use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Wastewater											
New England	0	1	0	0	0	0	0	0	0	0	0
Mid-Atlantic	1	0	0	0	0	0	0	0	0	0	0
South Atlantic-Gulf	0	0	0	0	0	0	0	0	0	0	0
Great Lakes	0	0	0	0	30	49	31	28	24	21	19
Ohio	0	0	0	0	0	0	0	0	0	0	0
Tennessee	0	0	0	0	0	0	0	0	0	0	0
Upper Mississippi	0	0	0	0	0	0	0	0	0	0	0
Lower Mississippi	0	0	0	0	0	0	0	0	0	0	0
Souris-Red-Rainy	0	0	0	0	0	0	0	0	0	0	0
Missouri Basin	24	0	88	80	2	3	2	2	2	1	1
Arkansas-White-Red	15	0	6	2	15	24	16	14	12	11	9
Texas-Gulf	9	5	14	31	55	89	57	51	44	39	35
Rio Grande	33	18	17	20	0	0	0	0	0	0	0
Upper Colorado	0	0	0	0	0	0	0	0	0	0	0
Lower Colorado	2	57	5	58	6	10	6	6	5	4	4
Great Basin	48	51	53	5	4	6	4	4	3	3	3
Pacific Northwest	0	3	6	9	17	28	18	16	14	12	11
California	430	400	120	160	150	244	156	138	121	107	95
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	0	0	57	0	0	0	0	0	0	0	0
Caribbean	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	562	535	366	365	279	453	290	257	225	199	176

Table A.2--Freshwater withdrawals for irrigation use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Total Withdrawals											
New England	10	27	80	57	53	42	42	45	47	49	51
Mid-Atlantic	82	122	127	234	247	238	238	253	268	279	290
South Atlantic-Gulf	798	3200	2400	3000	3800	3656	3656	3888	4111	4286	4449
Great Lakes	46	65	90	100	330	478	478	508	537	560	582
Ohio	12	24	35	34	148	101	101	107	114	118	123
Tennessee	14	8	6	7	7	18	18	19	20	21	22
Upper Mississippi	43	85	104	142	379	532	532	566	598	624	647
Lower Mississippi	850	1960	3200	4900	7700	6500	6499	6912	7309	7620	7910
Souris-Red-Rainy	13	25	12	42	64	159	159	169	179	186	193
Missouri Basin	13269	15700	18588	28880	29002	26465	26463	28144	29759	31024	32206
Arkansas-White-Red	4615	10200	8206	10002	10815	9869	9868	10495	11097	11569	12010
Texas-Gulf	6537	7105	6114	7031	5555	8744	8743	9299	9832	10250	10641
Rio Grande	5905	6418	5517	4820	4300	3924	3924	4173	4412	4600	4775
Upper Colorado	5613	6414	7853	3760	7481	6827	6826	7260	7676	8003	8307
Lower Colorado	5388	6157	6505	7558	7606	6941	6940	7381	7804	8136	8446
Great Basin	5208	4841	5913	6005	5904	5388	5388	5730	6059	6316	6557
Pacific Northwest	18900	26303	27006	28509	29117	26570	26568	28255	29877	31147	32333
California	16430	26400	34120	36160	38150	34813	34810	37021	39146	40810	42364
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	920	1160	1287	950	910	830	830	883	934	973	1011
Caribbean	280	253	140	260	320	417	417	443	469	489	507
Total Withdrawals	84933	116467	127303	142451	151888	142512	142500	151551	160248	167063	173423

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. In addition to the irrigation of crops, this data also includes irrigation of recreational facilities (e.g. golf courses and ski slopes) and other uses (e.g. landscape plantings) if water source is self-supplied. Data for 1985 from the Soil Conservation Service, modified by additional non-agricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.3--Freshwater withdrawals for municipal central supplies in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day)

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	170	260	330	280	330	421	565	679	795	890	949
Mid-Atlantic	670	890	1100	1300	1100	1402	1885	2263	2650	2966	3163
South Atlantic-Gulf	810	990	1300	1500	1900	2422	3256	3910	4577	5124	5464
Great Lakes	363	400	700	460	440	561	754	905	1060	1187	1265
Ohio	400	510	620	700	730	930	1251	1502	1758	1969	2099
Tennessee	73	71	64	79	89	113	153	183	214	240	256
Upper Mississippi	410	570	870	1200	1100	1402	1885	2263	2650	2966	3163
Lower Mississippi	210	270	390	470	610	777	1045	1255	1469	1645	1754
Souris-Red-Rainy	15	15	20	22	27	34	46	56	65	73	78
Missouri Basin	316	340	430	490	530	675	908	1091	1277	1429	1524
Arkansas-White-Red	265	310	250	370	320	408	548	658	771	863	920
Texas-Gulf	449	510	590	670	800	1020	1371	1646	1927	2157	2301
Rio Grande	141	160	180	280	240	306	411	494	578	647	690
Upper Colorado	12	19	28	26	23	29	39	47	55	62	66
Lower Colorado	148	230	250	320	370	472	634	761	891	998	1064
Great Basin	130	110	160	190	400	510	685	823	964	1079	1150
Pacific Northwest	350	410	460	460	530	675	908	1091	1277	1429	1524
California	1300	1900	1600	1700	1900	2422	3256	3910	4577	5124	5464
Alaska	8	12	24	35	23	29	39	47	55	62	66
Hawaii	74	100	120	170	180	229	308	370	434	485	518
Caribbean	7	19	34	59	75	96	129	154	181	202	216
Total Groundwater	6321	8096	9520	10781	11717	14933	20077	24110	28225	31597	33697

Table A.3--Freshwater withdrawals for municipal central supplies in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Surface Water											
New England	870	950	1100	1100	1200	1170	1638	1858	2071	2239	2341
Mid-Atlantic	3160	3140	4100	4000	4300	4193	5870	6659	7423	8023	8387
South Atlantic-Gulf	970	990	1400	1700	1900	1853	2594	2942	3280	3545	3706
Great Lakes	3000	3400	3700	2700	3500	3413	4778	5420	6042	6530	6827
Ohio	1100	1300	1500	1500	1500	1463	2048	2323	2589	2799	2926
Tennessee	240	180	240	250	320	312	437	496	552	597	624
Upper Mississippi	600	580	690	1800	820	800	1119	1270	1415	1530	1599
Lower Mississippi	170	230	220	280	310	302	423	480	535	578	605
Souris-Red-Rainy	18	21	25	26	30	29	41	46	52	56	59
Missouri Basin	510	630	590	720	850	829	1160	1316	1467	1586	1658
Arkansas-White-Red	360	420	490	570	1200	1170	1638	1858	2071	2239	2341
Texas-Gulf	490	460	550	690	2200	2145	3003	3407	3798	4105	4291
Rio Grande	100	94	130	74	74	72	101	115	128	138	144
Upper Colorado	37	34	30	51	100	98	137	155	173	187	195
Lower Colorado	73	66	140	190	350	341	478	542	604	653	683
Great Basin	140	160	160	190	410	400	560	635	708	765	800
Pacific Northwest	840	840	830	710	730	712	996	1130	1260	1362	1424
California	1400	2100	1800	2000	2200	2145	3003	3407	3798	4105	4291
Alaska	15	20	35	46	30	29	41	46	52	56	59
Hawaii	11	8	12	11	15	15	20	23	26	28	29
Caribbean	62	120	170	230	280	273	382	434	483	522	546
Total Surface Water	14166	15743	17912	18838	22319	21765	30466	34562	38527	41643	43532

Table A.3--Freshwater withdrawals for municipal central supplies in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Total Withdrawals											
New England	1040	1210	1430	1380	1530	1650	2265	2621	2971	3251	3466
Mid-Atlantic	3830	4030	5200	5300	5400	5822	7995	9250	10487	11473	12232
South Atlantic-Gulf	1780	1980	2700	3200	3800	4097	5626	6509	7380	8074	8608
Great Lakes	3363	3800	4400	3160	3940	4248	5833	6749	7652	8371	8925
Ohio	1500	1810	2120	2200	2230	2404	3302	3820	4331	4738	5052
Tennessee	313	251	304	329	409	441	606	701	794	869	926
Upper Mississippi	1010	1150	1560	3000	1920	2070	2843	3289	3729	4079	4349
Lower Mississippi	380	500	610	750	920	992	1362	1576	1787	1955	2084
Souris-Red-Rainy	33	36	45	48	57	61	84	98	111	121	129
Missouri Basin	826	970	1020	1210	1380	1488	2043	2364	2680	2932	3126
Arkansas-White-Red	625	730	740	940	1520	1639	2250	2604	2952	3230	3443
Texas-Gulf	935	970	1140	1360	3000	3235	4442	5139	5826	6374	6796
Rio Grande	245	254	310	354	314	339	465	538	610	667	711
Upper Colorado	41	53	58	77	123	133	182	211	239	261	279
Lower Colorado	229	296	390	510	720	776	1066	1233	1398	1530	1631
Great Basin	270	270	320	380	810	873	1199	1387	1573	1721	1835
Pacific Northwest	1190	1250	1290	1170	1260	1359	1865	2158	2447	2677	2854
California	2700	4000	3400	3700	4100	4421	6070	7023	7962	8711	9288
Alaska	23	32	59	81	53	57	78	91	103	113	120
Hawaii	85	108	132	181	195	210	289	334	379	414	442
Caribbean	69	139	204	289	355	383	526	608	689	754	804
Total Withdrawals	20487	23839	27432	29619	34036	36699	50392	58301	66100	72316	77100

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.4--Freshwater withdrawals for industrial self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day)

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	130	140	180	200	180	81	111	128	147	166	187
Mid-Atlantic	630	700	1000	630	580	261	438	505	579	656	737
South Atlantic-Gulf	1140	1300	1500	1900	1800	809	1031	1188	1362	1542	1734
Great Lakes	421	360	300	300	630	283	244	281	322	365	410
Ohio	600	890	750	740	1300	585	553	638	731	828	930
Tennessee	230	49	45	140	97	44	56	64	74	84	94
Upper Mississippi	480	620	630	690	650	292	390	450	516	584	657
Lower Mississippi	450	470	980	950	1000	450	581	670	767	869	977
Souris-Red-Rainy	5	7	5	2	4	2	2	3	3	3	4
Missouri Basin	183	270	360	400	380	171	226	261	299	338	380
Arkansas-White-Red	310	400	250	290	320	144	170	197	225	255	287
Texas-Gulf	352	340	390	340	240	108	192	222	254	288	323
Rio Grande	78	75	110	84	16	7	42	48	55	62	70
Upper Colorado	5	8	12	28	23	10	12	14	16	19	21
Lower Colorado	75	110	170	210	160	72	107	123	141	160	180
Great Basin	110	65	85	120	130	58	66	77	88	99	112
Pacific Northwest	400	400	620	2100	2300	1034	995	1147	1314	1489	1674
California	300	480	410	390	430	193	244	281	322	365	410
Alaska	12	7	8	0	6	3	3	3	4	4	5
Hawaii	110	65	160	97	9	4	53	61	70	79	89
Caribbean	29	38	40	72	85	38	39	45	52	58	66
Total Groundwater	6050	6794	8005	9683	10340	4650	5555	6405	7339	8314	9345

Table A.4--Freshwater withdrawals for industrial self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Surface Water											
New England	1100	1100	1100	1300	1300	898	907	987	1064	1139	1212
Mid-Atlantic	2830	3200	5600	3700	2900	2003	2990	3255	3508	3755	3995
South Atlantic-Gulf	1970	1600	2100	2600	4100	2832	2157	2348	2530	2709	2882
Great Lakes	7200	8700	8300	6900	5100	3523	4976	5416	5837	6249	6647
Ohio	6600	7700	5100	5200	3700	2556	3431	3735	4025	4309	4584
Tennessee	1200	1000	1300	1500	2000	1382	1176	1281	1380	1477	1572
Upper Mississippi	1200	1000	1100	1100	2600	1796	1176	1281	1380	1477	1572
Lower Mississippi	940	2100	3100	3300	3200	2211	2353	2561	2760	2955	3144
Souris-Red-Rainy	80	98	73	31	5	3	27	29	31	34	36
Missouri Basin	280	180	160	120	300	207	142	155	167	179	190
Arkansas-White-Red	681	440	370	630	530	366	375	408	440	471	501
Texas-Gulf	819	570	1000	330	280	193	395	430	463	496	527
Rio Grande	11	8	97	9	0	0	26	28	30	33	35
Upper Colorado	28	30	52	63	560	387	165	180	194	208	221
Lower Colorado	25	27	42	58	86	59	46	50	53	57	61
Great Basin	200	140	130	120	370	256	152	165	178	191	203
Pacific Northwest	1700	1400	1100	1300	1400	967	931	1014	1093	1170	1244
California	64	85	48	55	58	40	39	43	46	50	53
Alaska	70	95	100	90	120	83	76	83	89	95	102
Hawaii	33	51	100	94	36	25	56	61	66	71	75
Caribbean	130	140	180	98	30	21	75	82	89	95	101
Total Suface Water	27161	29664	31152	28598	28675	19810	21673	23591	25425	27218	28955

Table A.4--Freshwater withdrawals for industrial self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Wastewater											
New England	0	0	0	0	0	0	0	0	0	0	0
Mid-Atlantic	70	130	130	150	160	120	266	312	359	406	453
South Atlantic-Gulf	0	0	0	0	0	0	0	0	0	0	0
Great Lakes	0	0	0	0	0	0	0	0	0	0	0
Ohio	0	0	0	0	0	0	0	0	0	0	0
Tennessee	0	0	0	0	0	0	0	0	0	0	0
Upper Mississippi	0	0	0	0	0	0	0	0	0	0	0
Lower Mississippi	0	0	0	0	0	0	0	0	0	0	0
Souris-Red-Rainy	0	0	0	0	0	0	0	0	0	0	0
Missouri Basin	0	0	0	0	0	0	0	0	0	0	0
Arkansas-White-Red	0	2	5	4	0	0	5	6	7	8	9
Texas-Gulf	0	2	1	5	0	0	4	4	5	6	6
Rio Grande	0	4	0	0	0	0	0	0	0	0	0
Upper Colorado	0	0	0	0	0	0	0	0	0	0	0
Lower Colorado	0	1	0	7	12	9	11	13	15	18	20
Great Basin	0	0	0	1	1	1	1	1	2	2	2
Pacific Northwest	0	0	0	0	0	0	0	0	0	0	0
California	1	1	4	2	9	7	9	11	12	14	15
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	0	0	9	0	10	8	11	13	15	18	20
Caribbean	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	71	140	149	169	192	144	308	362	416	471	525

Table A.4--Freshwater withdrawals for industrial self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
<u>Total Withdrawals</u>											
New England	1230	1240	1280	1500	1480	928	996	1097	1199	1300	1401
Mid-Atlantic	3460	3900	6600	4330	3480	2182	3369	3712	4054	4397	4739
South Atlantic-Gulf	3110	2900	3600	4500	5900	3699	3273	3606	3939	4272	4604
Great Lakes	7621	9060	8600	7200	5730	3592	5034	5546	6057	6569	7081
Ohio	7200	8590	5850	5940	5000	3135	3926	4325	4724	5123	5522
Tennessee	1430	1049	1345	1640	2097	1315	1188	1309	1430	1551	1671
Upper Mississippi	1680	1620	1730	1790	3250	2038	1583	1744	1905	2066	2227
Lower Mississippi	1390	2570	4080	4250	4200	2633	2930	3227	3525	3823	4121
Souris-Red-Rainy	85	105	78	33	9	6	28	31	34	37	39
Missouri Basin	463	450	520	520	680	426	402	443	484	525	566
Arkansas-White-Red	991	840	620	920	850	533	559	616	672	729	786
Texas-Gulf	1168	910	1390	670	520	326	603	665	726	787	849
Rio Grande	106	83	207	93	16	10	74	81	89	96	104
Upper Colorado	29	38	64	91	583	365	173	190	208	225	243
Lower Colorado	104	137	212	268	246	154	170	187	204	222	239
Great Basin	310	205	215	240	500	313	223	246	269	291	314
Pacific Northwest	2100	1800	1720	3400	3700	2320	2062	2272	2482	2691	2901
California	364	565	458	445	488	306	325	358	391	424	457
Alaska	82	102	108	90	126	79	76	83	91	99	107
Hawaii	143	116	260	191	45	28	116	128	140	151	163
Caribbean	159	178	220	170	115	72	118	130	142	154	166
Total Withdrawals	33225	36458	39157	38281	39015	24460	27228	29996	32764	35532	38300

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.5--Freshwater withdrawals for domestic self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day)

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	37	95	94	110	130	129	171	191	209	223	231
Mid-Atlantic	260	270	340	380	430	428	566	632	691	738	764
South Atlantic-Gulf	320	540	460	510	720	717	948	1058	1158	1235	1279
Great Lakes	290	260	270	280	270	269	356	397	434	463	480
Ohio	190	240	240	280	290	289	382	426	466	497	515
Tennessee	57	64	51	42	61	61	80	90	98	105	108
Upper Mississippi	160	190	200	190	290	289	382	426	466	497	515
Lower Mississippi	50	63	110	77	94	94	124	138	151	161	167
Souris-Red-Rainy	10	13	19	24	23	23	30	34	37	39	41
Missouri Basin	98	94	110	130	210	209	277	309	338	360	373
Arkansas-White-Red	69	98	88	100	130	129	171	191	209	223	231
Texas-Gulf	30	33	80	100	120	119	158	176	193	206	213
Rio Grande	9	10	20	25	33	33	43	49	53	57	59
Upper Colorado	1	4	6	6	15	15	20	22	24	26	27
Lower Colorado	1	10	24	36	37	37	49	54	59	63	66
Great Basin	14	26	37	28	32	32	42	47	51	55	57
Pacific Northwest	39	95	220	220	230	229	303	338	370	394	409
California	190	81	120	120	130	129	171	191	209	223	231
Alaska	5	6	4	6	11	11	14	16	18	19	20
Hawaii	6	0	0	0	4	4	5	6	6	7	7
Caribbean	2	1	0	2	5	5	7	7	8	9	9
Total Groundwater	1838	2193	2493	2666	3265	3251	4300	4800	5250	5600	5800

Table A.5--Freshwater withdrawals for domestic self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Surface Water											
New England	2	5	2	2	1	0	1	1	0	0	0
Mid-Atlantic	2	1	2	2	2	1	1	1	1	0	0
South Atlantic-Gulf	0	0	2	2	0	0	0	0	0	0	0
Great Lakes	10	10	7	4	3	1	2	1	1	1	1
Ohio	31	41	33	25	21	10	11	9	6	4	4
Tennessee	1	0	1	0	0	0	0	0	0	0	0
Upper Mississippi	17	16	6	8	10	5	5	3	2	2	2
Lower Mississippi	5	1	0	1	1	0	1	0	0	0	0
Souris-Red-Rainy	0	0	0	0	0	0	0	0	0	0	0
Missouri Basin	15	12	11	14	22	10	9	7	5	4	4
Arkansas-White-Red	5	6	6	7	25	12	9	7	4	3	3
Texas-Gulf	0	0	0	0	0	0	0	0	0	0	0
Rio Grande	0	0	1	1	1	0	1	0	0	0	0
Upper Colorado	14	2	1	1	43	20	13	10	7	5	5
Lower Colorado	0	0	0	0	0	0	0	0	0	0	0
Great Basin	2	1	1	1	4	2	1	1	1	1	1
Pacific Northwest	30	6	29	34	32	15	17	12	8	6	6
California	17	9	9	9	9	4	5	3	2	2	2
Alaska	1	2	2	3	0	0	1	0	0	0	0
Hawaii	2	0	0	0	0	0	0	0	0	0	0
Caribbean	9	4	3	18	3	1	5	3	2	2	2
Total Surface Water	163	116	116	132	177	83	80	60	40	30	30

Table A.5--Freshwater withdrawals for domestic self-supplied use in the United States for 1960 to 1985, by water resource region,with projections of demand to 2040 (million gallons per day) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Total Withdrawals											
New England	39	100	96	112	131	127	167	186	202	241	222
Mid-Atlantic	262	271	342	382	432	418	550	615	665	707	732
South Atlantic-Gulf	320	540	462	512	720	697	916	1025	1109	1178	1220
Great Lakes	300	270	277	284	273	264	347	389	420	447	462
Ohio	221	281	273	305	311	301	396	443	479	509	527
Tennessee	58	64	52	42	61	59	78	87	942	100	103
Upper Mississippi	177	206	206	198	300	291	382	427	462	491	508
Lower Mississippi	55	64	110	78	95	92	121	135	146	155	161
Souris-Red-Rainy	10	13	19	24	23	22	29	33	35	38	39
Missouri Basin	113	106	121	144	232	225	295	330	357	379	393
Arkansas-White-Red	74	104	94	107	155	150	197	221	239	254	263
Texas-Gulf	33	33	80	100	120	116	153	171	185	196	203
Rio Grande	10	10	21	26	34	33	43	48	52	56	58
Upper Colorado	6	6	7	7	58	56	74	83	89	95	98
Lower Colorado	10	10	24	36	37	36	47	53	57	61	63
Great Basin	16	27	38	29	36	35	46	51	55	59	61
Pacific Northwest	69	101	249	254	262	254	333	373	403	429	444
California	207	90	129	129	139	135	177	198	214	227	235
Alaska	6	8	6	9	11	11	14	16	17	18	19
Hawaii	8	0	0	0	4	4	5	6	6	7	7
Caribbean	11	5	3	20	8	8	10	11	12	13	14
Total Withdrawals	2005	2309	2609	2798	3442	3334	4380	4900	5300	5630	5830

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.6--Freshwater withdrawals for livestock watering use in the United States from 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per year)

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	7	6	7	4	4	10	6	7	7	7	8
Mid-Atlantic	38	37	46	68	79	196	83	88	93	96	98
South Atlantic-Gulf	63	79	110	150	130	322	167	179	188	195	199
Great Lakes	64	57	62	60	64	159	80	85	90	93	95
Ohio	58	54	58	78	63	156	85	91	96	99	101
Tennessee	10	16	11	9	12	30	14	15	15	16	16
Upper Mississippi	200	260	200	200	220	546	266	284	299	310	316
Lower Mississippi	18	22	22	25	17	42	27	29	31	32	33
Souris-Red-Rainy	11	14	12	13	10	25	15	16	17	17	18
Missouri Basin	182	210	270	300	270	670	360	385	405	420	428
Arkansas-White-Red	56	60	66	86	85	211	102	109	114	118	121
Texas-Gulf	10	53	71	85	78	193	100	107	113	117	119
Rio Grande	8	38	17	18	26	64	26	28	29	30	31
Upper Colorado	1	2	6	6	2	5	6	6	7	7	7
Lower Colorado	9	16	18	32	12	30	27	28	30	31	32
Great Basin	10	23	35	38	34	84	46	49	52	53	54
Pacific Northwest	21	24	18	28	21	52	29	31	32	33	34
California	57	34	38	42	36	89	50	53	56	58	59
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	1	1	1	6	5	12	5	5	6	6	6
Caribbean	1	1	1	1	15	37	7	8	8	8	9
Total Groundwater	825	1007	1069	1249	1183	2934	1501	1603	1688	1749	1783

Table A.6--Freshwater withdrawals for livestock watering use in the United States from 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per year) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Surface Water											
New England	6	6	5	5	5	11	7	7	8	8	8
Mid-Atlantic	26	23	33	27	32	69	41	44	46	48	49
South Atlantic-Gulf	67	68	51	96	110	239	114	122	129	134	136
Great Lakes	28	22	24	25	20	43	31	33	35	36	37
Ohio	69	80	84	110	90	195	126	135	142	148	151
Tennessee	28	21	20	28	29	63	34	36	39	40	41
Upper Mississippi	91	56	60	63	51	111	77	82	87	90	92
Lower Mississippi	23	23	33	23	25	54	36	38	41	42	43
Souris-Red-Rainy	10	6	2	3	4	9	4	4	5	5	5
Missouri Basin	137	160	170	180	120	261	208	223	235	244	249
Arkansas-White-Red	86	93	120	140	150	326	182	194	205	213	217
Texas-Gulf	8	37	42	51	120	261	94	101	107	111	113
Rio Grande	6	31	20	20	6	13	20	22	23	24	24
Upper Colorado	8	9	12	9	91	198	50	53	56	58	59
Lower Colorado	3	3	10	17	5	11	14	15	16	17	17
Great Basin	11	6	6	10	12	26	12	13	14	15	15
Pacific Northwest	38	35	34	25	34	74	41	44	47	48	49
California	25	50	54	58	50	109	72	77	81	84	86
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	2	3	6	0	0	0	3	3	3	3	3
Caribbean	3	5	8	8	15	33	14	15	16	16	16
Total Surface Water	675	737	794	898	969	2104	1179	1261	1332	1383	1411

Table A.6--Freshwater withdrawals for livestock watering use in the United States from 1960 to 1985, by water resource region, with projections of demand to 2040 (million gallons per year) - Continued

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Total Withdrawals											
New England	13	12	12	9	9	21	13	14	15	15	16
Mid-Atlantic	64	60	79	95	111	260	124	132	140	145	148
South Atlantic-Gulf	130	147	161	246	240	562	282	301	317	329	335
Great Lakes	92	79	86	85	84	197	111	119	125	130	132
Ohio	127	134	142	188	153	358	210	224	237	245	250
Tennessee	38	37	31	37	41	96	47	51	53	55	57
Upper Mississippi	291	316	260	263	271	634	346	369	389	403	412
Lower Mississippi	41	45	55	48	42	98	63	67	71	74	75
Souris-Red-Rainy	21	20	14	16	14	33	19	20	22	22	23
Missouri Basin	319	370	440	480	390	913	570	609	642	666	679
Arkansas-White-Red	142	153	186	226	235	550	282	301	317	329	335
Texas-Gulf	18	90	113	136	198	463	195	208	219	227	232
Rio Grande	14	69	37	38	32	75	47	50	52	54	55
Upper Colorado	8	11	18	15	93	218	55	59	62	64	65
Lower Colorado	14	19	28	49	17	40	41	44	46	48	49
Great Basin	21	29	41	48	46	108	59	63	66	69	70
Pacific Northwest	59	59	52	53	55	129	70	74	78	81	83
California	82	84	92	100	86	201	121	129	136	141	144
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	3	4	7	6	5	12	8	8	9	9	9
Caribbean	4	6	9	9	30	70	21	22	24	24	25
Total Withdrawals	1501	1744	1863	2147	2152	5038	2683	2864	3020	3131	3195

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.7--Freshwater withdrawals for thermoelectric steam cooling use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040 (million gallons per day)

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	3	1	1	2	2	1	1	1	1	1	1
Rocky Mountain	26	79	341	347	89	65	72	71	71	70	69
Southwestern	23	23	49	52	51	43	48	47	47	46	46
Intermountain	0	1	7	14	12	17	19	19	19	19	18
Pacific Southwest	303	330	383	521	1020	95	106	104	103	102	102
Pacific Northwest	0	0	0	0	0	1	1	1	1	1	1
Southern	530	618	167	172	208	201	223	220	217	215	214
Eastern	36	62	486	300	208	206	229	226	223	221	220
Alaskan	0	1	1	2	8	4	5	5	5	5	5
Total Groundwater	920	1115	1435	1410	1598	633	703	694	686	679	676
Surface Water											
Northern	65	136	413	780	1101	958	1153	1284	1414	1544	1675
Rocky Mountain	1526	984	1095	1119	2842	2873	3457	3848	4239	4630	5020
Southwestern	51	16	22	132	103	69	83	92	102	111	121
Intermountain	128	198	175	136	192	74	89	99	109	119	129
Pacific Southwest	152	697	1254	1131	1110	416	500	557	614	670	727
Pacific Northwest	3698	5	26	29	23	439	528	588	648	707	767
Southern	22571	27311	39400	48258	58076	49796	59926	66700	73475	80249	87021
Eastern	44849	61154	75865	78019	83295	75592	90970	101254	111538	121821	132101
Alaskan	86	1	68	18	22	26	31	35	38	42	45
Total Surface Water	73125	90503	118319	129622	146764	130243	156738	174457	192176	209893	227606
Total Withdrawals											
Northern	68	137	414	781	1103	959	0	1284	1413	1543	1673
Rocky Mountain	1552	1063	1437	1465	2931	2938	3534	3932	4329	4727	5124
Southwestern	74	39	71	184	154	112	135	150	165	180	195
Intermountain	128	199	182	150	204	91	110	122	135	147	159
Pacific Southwest	455	1027	1639	1651	2131	511	614	684	753	822	891
Pacific Northwest	3698	5	26	29	23	440	529	588	648	707	767
Southern	23101	27929	39565	48432	58284	49996	60145	66910	73676	80441	87207
Eastern	44883	61217	76349	78321	83502	75798	91184	101441	111698	121955	132212
Alaskan	86	2	69	20	30	30	36	41	45	49	53
Total Withdrawals	74045	91618	119754	131032	148362	130876	157441	175151	192862	210572	228282

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.8--Freshwater withdrawals for irrigation use in the United States for 1960 to 1985, by Forest Servcie Region, with projections of demand to 2040 (million gallons per day)

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	541	626	551	929	1085	878	867	910	950	977	1001
Rocky Mountain	4077	5170	7534	12564	15037	12127	11972	12569	13118	13496	13823
Southwestern	3910	5100	5100	5500	5300	3670	3623	3804	3970	4084	4183
Intermountain	2442	3058	2469	3802	4341	3783	3735	3921	4092	4210	4312
Pacific Southwest	8880	11590	16550	17430	18460	11436	11290	11853	12371	12727	13036
Pacific Northwest	660	740	980	1150	1110	1100	1086	1140	1190	1224	1254
Southern	9819	15429	12054	15300	14759	12645	12484	13107	13679	14073	14414
Eastern	127	280	296	429	862	857	846	888	927	953	977
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Groundwater	30403	41572	45251	57074	61153	56292	55575	58347	60894	62649	64167
Surface Water											
Northern	6977	9314	10634	13771	12864	12128	12250	13143	14017	14736	15424
Rocky Mountain	11521	15999	17695	14652	17969	17310	17485	18759	20007	21033	22015
Southwestern	2620	3500	3900	4400	5400	4670	4717	5061	5398	5674	5939
Intermountain	11823	15653	16967	16231	15551	20364	20570	22069	23537	24745	25900
Pacific Southwest	9940	14580	17680	18520	19450	21070	21283	22834	24353	25602	26797
Pacific Northwest	7900	9300	9500	10400	11100	9550	9647	10349	11038	11604	12146
Southern	2706	5909	4956	5884	7034	6174	6236	6691	7136	7502	7852
Eastern	110	140	217	256	435	430	434	466	497	522	546
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Surface Water	54069	74360	81686	85012	90456	85767	86635	92947	99129	104215	109080
Wastewater											
Northern	0	0	0	1	3	0	1	1	1	1	1
Rocky Mountain	39	0	86	80	2	5	23	20	18	16	14
Southwestern	0	78	22	54	3	29	23	20	18	16	14
Intermountain	48	52	59	9	13	17	10	9	8	7	6
Pacific Southwest	430	400	177	160	150	253	149	132	116	102	90
Pacific Northwest	0	3	3	4	4	5	3	3	3	2	2
Southern	34	0	15	53	70	119	64	57	50	44	39
Eastern	10	1	0	0	30	26	15	13	11	10	9
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	562	535	366	365	279	453	290	257	225	199	176

Table A.8--Freshwater withdrawals for irrigation use in the United States for 1960 to 1985, by Forest Servcie Region, with projections of demand to 2040 (million gallons per day) - Continued

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Total Withdrawals											
Northern	7518	9940	11186	14701	13952	13006	13005	13831	14624	15246	15827
Rocky Mountain	15637	21169	25316	27295	33008	29441	29439	31309	33105	34513	35827
Southwestern	6530	8678	9022	9954	10703	8369	8368	8900	9411	9811	10184
Intermountain	14313	18763	19495	20041	19905	24164	24162	25696	27171	28327	29405
Pacific Southwest	19250	26570	34407	36110	38060	32759	32757	34837	36836	38403	39865
Pacific Northwest	8560	10043	10483	11554	12214	10655	10654	11330	11981	12490	12966
Southern	12559	21338	17025	21237	21863	18938	18936	20139	21294	22200	23045
Eastern	247	421	513	685	1327	1312	1312	1395	1475	1538	1597
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Withdrawals	84933	116467	127303	142451	151888	142512	142500	151551	160248	167063	173423

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. In addition to the irrigation of crops, this data also includes irrigation of recreational facilities (e.g. golf courses and ski slopes) and other uses (e.g. landscape plantings) if water source is self-supplied. Data for 1985 from the Soil Conservation Service, modified by additional non-agricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.9--Freshwater withdrawals for municipal central supplies in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040 (million gallons per day)

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	62	66	75	94	113	135	182	218	256	286	305
Rocky Mountain	350	353	419	471	466	550	740	889	1040	1165	1242
Southwestern	184	261	322	443	488	583	784	941	1102	1234	1316
Intermountain	221	256	313	345	593	538	723	868	1016	1137	1213
Pacific Southwest	1276	1995	1730	1884	2072	4202	5649	6784	7942	8891	9482
Pacific Northwest	371	311	359	337	365	422	567	681	798	893	952
Southern	1796	2185	2626	3182	3811	4471	6011	7219	8451	9460	10089
Eastern	2053	2657	3652	3989	3786	3991	5366	6443	7543	8444	9006
Alaskan	8	12	24	35	23	41	55	66	77	87	93
Total Ground Water	6321	8096	9520	10781	11717	14933	20077	24110	28225	31597	33697
Surface Water											
Northern	115	95	116	121	132	143	200	227	253	273	286
Rocky Mountain	418	532	500	637	813	911	1275	1447	1613	1743	1822
Southwestern	66	71	136	147	281	261	365	414	462	499	522
Intermountain	183	193	200	265	533	374	523	594	662	716	748
Pacific Southwest	1410	2068	1810	2018	2216	1461	2045	2320	2586	2795	2922
Pacific Northwest	789	775	769	662	670	948	1327	1505	1678	1814	1896
Southern	2531	2801	3630	4258	6986	6322	8850	10039	11191	12096	12645
Eastern	8640	9187	10716	10683	10658	11310	15831	17960	20020	21639	22621
Alaskan	15	20	35	46	30	35	49	56	62	67	70
Total Surface Water	14166	15743	17912	18838	22319	21765	30466	34562	38527	41643	43532
Total Withdrawals											
Northern	177	160	191	215	244	278	382	442	501	548	584
Rocky Mountain	768	885	919	1108	1279	1462	2007	2322	2633	2880	3071
Southwestern	250	330	457	590	770	844	1159	1341	1520	1663	1773
Intermountain	403	447	512	609	1127	912	1252	1448	1642	1796	1915
Pacific Southwest	2684	4054	3536	3900	4290	5663	7776	8996	10200	11159	11897
Pacific Northwest	1160	1087	1128	1000	1035	1370	1881	2176	2468	2700	2878
Southern	4326	4978	6253	7439	10798	10794	14821	17147	19441	21269	22676
Eastern	10696	11867	14378	14677	14439	15301	21010	24308	27559	30151	32146
Alaskan	23	32	59	81	53	76	104	121	137	150	160
Total Withdrawals	20487	23839	27432	29619	34036	36699	50392	58301	66100	72316	77100

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates base upon trends in the historical data.

Table A.10--Freshwater withdrawals for industrial self-supplied use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040 (million gallons per day)

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	57	48	114	446	497	76	91	104	120	136	152
Rocky Mountain	230	210	342	385	332	156	186	215	246	279	313
Southwestern	79	171	222	254	147	68	82	94	108	122	137
Intermountain	175	155	373	1625	1804	187	223	257	295	334	375
Pacific Southwest	415	542	569	485	430	420	502	579	663	751	844
Pacific Northwest	211	298	260	209	230	159	190	219	251	284	320
Southern	2747	2621	3268	3716	3646	1872	2236	2578	2954	3346	3761
Eastern	2124	2743	2849	2563	3248	1704	2036	2348	2690	3048	3425
Alaskan	12	7	8	0	6	8	10	11	13	14	16
Total Groundwater	6050	6794	8005	9683	10340	4650	5555	6405	7339	8314	9345
Surface Water											
Northern	193	112	149	120	108	40	44	48	51	55	58
Rocky Mountain	221	181	187	198	827	146	160	174	188	201	214
Southwestern	20	26	38	25	20	8	9	10	10	11	12
Intermountain	233	212	260	277	564	38	42	46	49	53	56
Pacific Southwest	76	102	128	136	81	121	132	144	155	166	177
Pacific Northwest	3234	1242	998	1130	1245	674	737	803	865	926	985
Southern	6473	6454	9089	9262	10524	7711	8437	9183	9897	10595	11271
Eastern	16641	21241	20202	17360	15187	10965	11996	13058	14073	15066	16027
Alaskan	71	94	100	90	120	106	116	126	136	146	155
Total Surface Water	27161	29664	31152	28598	28675	19810	21673	23591	25425	27218	28955
Wastewater											
Northern	0	0	0	0	0	0	0	0	0	0	0
Rocky Mountain	0	0	0	0	0	0	0	0	0	0	0
Southwestern	0	0	0	0	2	5	4	5	6	6	7
Intermountain	0	1	0	8	11	0	12	14	16	18	20
Pacific Southwest	1	1	13	2	19	3	15	17	20	22	25
Pacific Northwest	0	0	0	0	0	1	0	0	0	1	1
Southern	0	7	6	9	0	55	39	46	53	60	66
Eastern	70	131	130	150	160	81	238	280	322	364	406
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	71	140	149	169	192	144	308	362	416	471	525

Table A.10--Freshwater withdrawals for industrial self-supplied use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040 (million gallons per day) - Continued

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Total Withdrawals											
Northern	250	160	264	567	605	116	129	142	155	168	181
Rocky Mountain	454	391	528	584	1161	302	336	370	405	439	473
Southwestern	101	197	260	280	167	76	85	94	102	111	120
Intermountain	411	366	634	1907	2366	225	251	276	302	327	353
Pacific Southwest	498	644	697	623	510	541	602	663	724	786	847
Pacific Northwest	3437	1540	1258	1339	1480	833	927	1022	1116	1210	1304
Southern	9247	9075	12358	12979	14203	9583	10667	11752	12836	13921	15005
Eastern	18745	23985	23052	19912	18488	12670	14103	15537	16971	18405	19838
Alaskan	83	101	108	90	126	114	127	140	153	166	179
Total Withdrawals	33225	36458	39157	38281	39105	24460	27228	29996	32764	35532	38300

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.11--Freshwater withdrawals for domestic self-supplied use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040 (million gallons per day)

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	23	27	32	44	82	48	61	68	74	79	81
Rocky Mountain	71	80	97	110	168	105	134	148	162	172	178
Southwestern	37	10	38	56	64	64	81	90	98	104	108
Intermountain	24	46	47	54	73	80	101	112	122	130	134
Pacific Southwest	202	79	120	120	133	131	166	184	201	213	221
Pacific Northwest	18	74	203	189	169	168	213	236	258	274	283
Southern	542	888	869	928	1238	1115	1416	1568	1709	1815	1877
Eastern	915	984	1083	1160	1327	1531	1945	2153	2347	2492	2578
Alaskan	5	6	4	6	11	9	11	13	14	15	15
Total Groundwater	1838	2193	2493	2666	3265	3251	4131	4573	4985	5293	5475
Surface Water											
Northern	1	0	2	1	1	0	0	0	0	0	0
Rocky Mountain	4	9	7	7	68	3	5	5	5	5	5
Southwestern	3	2	1	1	1	1	2	2	2	2	2
Intermountain	3	2	2	4	6	2	3	3	3	3	3
Pacific Southwest	22	9	9	9	10	30	47	47	47	47	47
Pacific Northwest	30	5	26	30	30	10	15	15	15	15	15
Southern	22	25	17	29	14	16	25	25	25	25	25
Eastern	77	63	50	47	47	20	31	31	31	31	31
Alaskan	1	2	2	3	0	1	1	1	1	1	1
Total Surface Water	163	116	116	132	177	83	129	129	129	129	129
Total Withdrawals											
Northern	25	27	34	45	83	48	68	76	83	89	92
Rocky Mountain	76	89	104	117	235	109	152	170	187	200	207
Southwestern	41	12	39	57	65	65	91	102	113	120	125
Intermountain	27	48	49	58	79	82	115	128	141	150	156
Pacific Southwest	224	87	129	129	143	161	225	252	277	296	307
Pacific Northwest	46	78	229	219	199	178	248	278	306	326	338
Southern	567	912	887	958	1253	1131	1582	1772	1946	2077	2154
Eastern	994	1047	1133	1207	1374	1550	2169	2429	2668	2847	2953
Alaskan	6	8	6	9	11	10	14	15	17	18	18
Total Withdrawals	2005	2309	2609	2798	3442	3334	4664	5224	5737	6123	6351

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.12--Freshwater withdrawals for livestock watering use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040 (million gallons per day)

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	17	35	36	42	36	258	132	141	149	154	157
Rocky Mountain	136	167	208	236	225	179	92	98	103	107	109
Southwestern	19	42	32	43	20	36	18	20	21	21	22
Intermountain	16	38	45	55	43	851	436	465	490	507	517
Pacific Southwest	58	35	39	48	42	42	21	23	24	25	25
Pacific Northwest	11	13	7	7	11	25	13	14	14	15	15
Southern	180	220	277	346	326	992	507	542	571	591	603
Eastern	388	456	426	472	479	541	277	296	311	322	329
Alaskan	0	0	0	0	0	10	5	5	6	6	6
Total Groundwater	825	1007	1069	1249	1183	2934	1501	1603	1688	1749	1783
Surface Water											
Northern	49	40	27	28	26	45	31	33	35	36	37
Rocky Mountain	72	91	119	99	173	126	211	225	238	247	252
Southwestern	9	37	40	44	12	75	14	15	16	17	17
Intermountain	21	17	18	16	29	30	36	38	40	42	43
Pacific Southwest	26	51	59	59	51	162	61	66	69	72	74
Pacific Northwest	26	24	21	21	21	813	25	27	29	30	30
Southern	243	263	281	359	475	542	577	618	652	677	691
Eastern	230	215	228	272	183	165	223	239	252	262	267
Alaskan	0	0	0	0	0	146	0	0	0	0	0
Total Surface Water	675	737	794	898	969	2104	1179	1261	1332	1383	1411
Total Withdrawals											
Northern	66	75	63	70	61	303	162	173	182	189	192
Rocky Mountain	209	258	328	335	399	305	162	173	183	190	194
Southwestern	27	79	72	87	32	111	59	63	67	69	70
Intermountain	37	56	63	70	72	881	469	501	528	548	559
Pacific Southwest	84	86	98	108	93	204	108	116	122	127	129
Pacific Northwest	37	37	28	28	32	838	446	476	502	521	531
Southern	421	485	558	705	803	1534	817	872	920	953	973
Eastern	620	670	654	744	660	706	376	401	423	439	448
Alaskan	0	0	0	0	0	156	83	89	93	97	99
Total Withdrawals	1501	1744	1863	2147	2152	5038	2683	2864	3020	3131	3195

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates through 2040 are Forest Service estimates based upon trends in historical data.

Table A.13--Freshwater consumption for thermoelectric steam cooling use in the United States for 1960 to 1985 by Water Resource region and Forest Service region, with projections of demand to 2040 (million gallons per day)

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	1	3	3	96	21	31	50	60	68	78	91
Mid-Atlantic	15	27	35	140	260	389	623	747	843	969	1122
South Atlantic-Gulf	7	11	120	210	270	404	647	775	875	1006	1165
Great Lakes	12	11	14	52	93	139	223	267	301	346	401
Ohio	33	17	50	280	520	778	1246	1493	1685	1937	2245
Tennessee	0	8	64	59	20	30	48	57	65	75	86
Upper Mississippi	4	27	23	96	290	434	695	833	940	1080	1252
Lower Mississippi	19	20	190	290	400	598	959	1149	1296	1490	1727
Souris-Red-Rainy	2	1	1	1	1	1	2	3	3	4	4
Missouri Basin	12	31	34	68	350	523	839	1005	1134	1304	1511
Arkansas-White-Red	29	54	82	95	410	613	982	1177	1329	1527	1770
Texas-Gulf	52	140	100	380	360	538	863	1034	1167	1341	1554
Rio Grande	4	11	17	20	11	16	26	32	36	41	47
Upper Colorado	8	18	22	60	130	194	312	373	421	484	561
Lower Colorado	7	15	36	47	49	73	117	141	159	183	212
Great Basin	2	2	6	6	6	9	14	17	19	22	26
Pacific Northwest	0	0	0	9	2	3	5	6	6	7	9
California	17	18	24	32	41	61	98	118	133	153	177
Alaska	0	0	0	1	0	0	0	0	0	0	0
Hawaii	0	0	0	0	0	0	0	0	0	0	0
Caribbean	0	1	0	5	6	9	14	17	19	22	26
U.S. Total	224	415	821	1947	3240	4846	7764	9303	10499	12070	13985
Forest Service region											
Northern	2	2	1	20	26	41	66	79	89	102	118
Rocky Mountain	22	46	53	77	197	113	181	216	244	281	325
Southwestern	20	31	59	74	106	96	154	184	208	239	277
Intermountain	4	4	13	36	39	51	82	98	111	128	148
Pacific Southwest	17	18	24	32	41	26	41	50	56	65	75
Pacific Northwest	10	0	0	7	1	25	40	48	54	62	72
Southern	96	228	568	1061	1536	1085	1739	2083	2351	2703	3132
Eastern	53	87	106	630	1294	3406	5457	6539	7379	8483	9829
Alaskan	0	0	0	1	0	3	5	6	7	8	9
Total Consumption	224	415	821	1947	3240	4846	7764	9303	10499	12070	13985

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.14--Freshwater consumption for irrigation use in the United States for 1960 to 1985 by Water Resource region and Forest Service region, with projections of demand to 2040 (million gallons per day)

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	7	26	64	57	52	46	55	57	60	61	63
Mid-Atlantic	82	122	120	200	240	212	253	264	275	284	292
South Atlantic-Gulf	797	1400	1500	1500	2300	2028	2421	2531	2637	2720	2797
Great Lakes	45	64	87	94	330	291	347	363	378	390	401
Ohio	12	24	35	32	150	132	158	165	172	177	182
Tennessee	14	8	7	7	7	6	7	8	8	8	9
Upper Mississippi	44	77	95	140	370	326	389	407	424	438	450
Lower Mississippi	660	1200	2200	4000	4800	4232	5053	5283	5504	5677	5838
Souris-Red-Rainy	9	17	12	41	60	53	63	66	69	71	73
Missouri Basin	6946	9800	12000	14000	15000	13225	15790	16509	17199	17740	18245
Arkansas-White-Red	3390	7700	6000	8000	8200	7229	8632	9025	9402	9698	9974
Texas-Gulf	4798	5500	4900	6500	4900	4320	5158	5393	5618	5795	5960
Rio Grande	3402	3900	3000	3200	2100	1851	2211	2311	2408	2484	2554
Upper Colorado	3505	3200	4000	1500	2000	1763	2105	2201	2293	2365	2433
Lower Colorado	3395	3100	4700	5700	4300	3791	4527	4732	4930	5085	5230
Great Basin	3300	3000	2900	3400	3500	3086	3684	3852	4013	4139	4257
Pacific Northwest	8000	10000	10000	9900	11000	9698	11580	12106	12612	13009	13379
California	13000	16000	21000	21000	23000	20278	24212	25313	26371	27201	27975
Alaska	0	0	1	0	0	0	0	0	0	0	0
Hawaii	370	530	750	500	610	538	642	671	699	721	742
Caribbean	250	230	98	150	200	176	211	220	229	237	243
U.S. Total	52026	65898	73469	79921	83119	73282	87498	91479	95303	98301	101098
Forest Service region											
Northern	3471	5750	6663	3901	4109	3041	3631	3796	3955	4079	4196
Rocky Mountain	9193	12029	14586	16513	17656	15997	19101	19970	20804	21459	22069
Southwestern	4224	4436	5882	6812	5706	4439	5301	5542	5773	5955	6124
Intermountain	7186	8276	7624	7773	8770	8211	9804	10250	10679	11015	11328
Pacific Southwest	14453	15659	21044	21537	23636	18818	22469	23491	24473	25243	25961
Pacific Northwest	4124	4436	4564	5209	5606	6889	8225	8600	8959	9241	9504
Southern	9143	14913	12646	17564	16356	14699	17550	18349	19116	19717	20278
Eastern	233	398	460	613	1278	1187	1417	1481	1543	1592	1637
Alaskan	0	0	1	0	0	0	0	0	0	0	0
Total Consumption	52026	65898	73469	79921	83119	73282	87498	91479	95303	98301	101098

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. In addition to the irrigation of crops this data also includes irrigation of recreational facilities (e.g. golf courses and ski slopes) and other uses (e.g. landscape plantings) if water source is self-supplied. Data for 1985 from the Soil Conservation Service, modified by additional non-agricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.15--Freshwater consumption for municipal central supplies in the United States for 1960 to 1985 by Water Resource region and Forest Service region, with projections of demand to 2040 (million gallons per day)

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	150	160	190	180	150	130	217	239	258	272	280
Mid-Atlantic	452	681	750	760	710	615	1027	1132	1223	1289	1326
South Atlantic-Gulf	300	360	590	930	780	676	1128	1244	1344	1416	1457
Great Lakes	400	520	500	410	310	269	448	494	534	563	579
Ohio	190	230	270	240	240	208	347	383	414	436	448
Tennessee	60	46	36	40	44	38	64	70	76	80	82
Upper Mississippi	130	160	190	170	180	156	260	287	310	327	336
Lower Mississippi	110	200	240	310	400	347	578	638	689	726	747
Souris-Red-Rainy	9	11	19	20	22	19	32	35	38	40	41
Missouri Basin	212	240	250	290	360	312	521	574	620	653	672
Arkansas-White-Red	196	260	250	330	310	269	448	494	534	563	579
Texas-Gulf	396	350	380	560	550	477	795	877	948	998	1027
Rio Grande	124	110	150	190	140	121	202	223	241	254	261
Upper Colorado	10	14	19	26	41	36	59	65	71	74	77
Lower Colorado	110	150	190	240	390	338	564	622	672	708	728
Great Basin	67	69	140	140	310	269	448	494	534	563	579
Pacific Northwest	150	210	260	230	290	251	419	463	500	526	542
California	370	1300	1400	1500	1700	1473	2458	2711	2929	3086	3175
Alaska	0	7	11	4	33	29	48	53	57	60	62
Hawaii	25	38	46	55	60	52	87	96	103	109	112
Caribbean	11	21	43	42	75	65	108	120	129	136	140
U.S. Total	3472	5137	5924	6667	7095	6149	10259	11316	12226	12878	13250
Forest Service region											
Northern	74	61	91	87	99	86	143	158	171	180	185
Rocky Mountain	191	241	235	275	348	302	503	555	600	632	650
Southwestern	123	161	227	283	438	380	634	699	755	795	818
Intermountain	108	121	202	212	417	362	603	665	719	757	779
Pacific Southwest	395	1324	1455	1557	1757	1522	2540	2802	3027	3188	3280
Pacific Northwest	113	186	209	176	217	188	313	345	373	393	404
Southern	1139	1301	1612	2323	2172	1882	3140	3464	3742	3942	4056
Eastern	1329	1735	1881	1749	1615	1399	2335	2575	2783	2931	3016
Alaskan	0	7	11	4	33	29	48	53	57	60	62
Total Consumption	3472	5137	5924	6667	7095	6149	10259	11316	12226	12878	13250

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.16--Freshwater consumption for industrial self-supplied use in the United States for 1960 to 1985 by Water Resource region and Forest Service region, with projections of demand to 2040 (million gallons per day)

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
<u>Water resource region</u>											
New England	84	79	96	64	66	72	88	100	112	123	135
Mid-Atlantic	460	470	330	340	280	307	375	424	473	523	573
South Atlantic-Gulf	430	260	540	540	1100	1204	1473	1665	1859	2054	2249
Great Lakes	280	360	450	370	370	405	495	560	625	691	757
Ohio	310	410	260	360	420	460	562	636	710	784	859
Tennessee	240	170	72	120	220	241	295	333	372	411	450
Upper Mississippi	36	58	75	98	170	186	228	257	287	317	348
Lower Mississippi	380	450	780	810	740	810	991	1120	1251	1382	1513
Souris-Red-Rainy	7	2	6	5	6	7	8	9	10	11	12
Missouri Basin	55	71	65	52	77	84	103	117	130	144	157
Arkansas-White-Red	185	330	210	270	330	361	442	500	558	616	675
Texas-Gulf	239	350	580	290	350	383	469	530	592	653	716
Rio Grande	31	46	97	55	13	14	17	20	22	24	27
Upper Colorado	5	8	21	27	63	69	84	95	106	118	129
Lower Colorado	32	51	100	190	150	164	201	227	254	280	307
Great Basin	9	36	62	63	100	109	134	151	169	187	204
Pacific Northwest	91	83	150	310	350	383	469	530	592	653	716
California	80	110	170	180	190	208	254	288	321	355	389
Alaska	0	4	4	0	1	1	1	2	2	2	2
Hawaii	13	4	4	4	0	0	0	0	0	0	0
Caribbean	7	10	18	37	20	22	27	30	34	37	41
U.S. Total	2974	3362	4090	4185	5016	5492	6715	7594	8478	9365	10257
<u>Forest Service region</u>											
Northern	32	24	28	50	57	33	41	46	51	57	62
Rocky Mountain	54	71	113	119	165	172	211	238	266	294	322
Southwestern	28	92	137	221	125	159	194	220	245	271	297
Intermountain	43	61	100	211	278	47	57	65	72	80	87
Pacific Southwest	95	114	175	183	191	679	830	939	1048	1158	1268
Pacific Northwest	154	64	126	149	171	159	194	220	245	271	297
Southern	1524	1581	2220	2075	2781	1945	2378	2690	3003	3317	3633
Eastern	1045	1351	1187	1177	1247	2282	2790	3155	3523	3891	4262
Alaskan	0	4	4	0	1	16	19	22	24	27	29
Total Consumption	2974	3362	4090	4185	5016	5492	6715	7594	8478	9365	10257

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.17--Freshwater consumption for domestic self-supplied use in the United Sttes for 1960 to 1985 by Water Resource region and Forest Service region, with projections of demand to 2040 (million gallons per day)

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	31	84	47	36	63	46	48	49	50	51	51
Mid-Atlantic	86	88	130	100	110	106	112	115	117	119	120
South Atlantic-Gulf	310	490	360	340	440	357	375	385	392	398	401
Great Lakes	96	100	78	61	74	67	70	72	73	74	75
Ohio	140	200	180	140	200	163	171	175	179	182	183
Tennessee	54	61	31	25	39	30	31	32	33	33	33
Upper Mississippi	73	100	130	48	190	115	121	124	127	128	130
Lower Mississippi	52	58	100	68	67	74	77	79	81	82	83
Souris-Red-Rainy	7	14	19	11	23	17	17	18	18	19	19
Missouri Basin	89	85	96	110	170	118	124	127	129	131	132
Arkansas-White-Red	70	96	84	97	120	94	99	102	104	105	106
Texas-Gulf	29	33	80	100	120	94	99	101	103	105	106
Rio Grande	6	7	13	17	18	15	16	16	17	17	17
Upper Colorado	2	2	3	3	17	7	8	8	8	8	8
Lower Colorado	6	5	17	27	27	22	23	24	24	25	25
Great Basin	8	15	13	6	14	10	11	11	11	12	12
Pacific Northwest	23	75	200	180	200	182	191	196	200	202	204
California	120	51	73	76	84	73	77	79	80	81	82
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	6	0	0	0	3	1	1	1	1	1	1
Caribbean	9	4	3	4	2	3	3	3	3	3	3
U.S. Total	1217	1568	1657	1449	1981	1592	1675	1716	1751	1776	1791
Forest Service region											
Northern	12	24	29	40	75	45	47	49	50	50	51
Rocky Mountain	68	80	88	97	152	106	111	114	116	118	119
Southwestern	31	8	24	37	39	31	33	34	35	35	35
Intermountain	9	23	19	14	27	19	20	20	21	21	21
Pacific Southwest	133	50	71	74	85	72	76	78	79	81	81
Pacific Northwest	18	67	190	169	168	165	173	178	181	184	185
Southern	519	798	721	661	842	696	732	750	766	777	783
Eastern	427	517	513	356	594	458	482	494	504	511	515
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Consumption	1217	1568	1657	1449	1981	1592	1675	1716	1751	1776	1791

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.18--Freshwater consumption for livestock watering use in the United States for 1960 to 1985 by Water Resource region and Forest Service region, with projections of demand to 2040 (million gallons per day)

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	13	11	12	9	9	11	11	12	12	12	13
Mid-Atlantic	58	51	65	76	86	103	105	110	116	119	121
South Atlantic-Gulf	127	140	150	240	240	287	292	308	323	333	338
Great Lakes	85	72	82	78	77	92	94	99	103	107	109
Ohio	130	130	140	170	140	168	170	180	188	194	197
Tennessee	38	36	30	32	40	48	49	51	54	55	56
Upper Mississippi	290	300	250	250	270	323	328	347	363	374	381
Lower Mississippi	41	44	55	47	41	49	50	53	55	57	58
Souris-Red-Rainy	21	19	15	16	14	17	17	18	19	19	20
Missouri Basin	301	360	410	440	380	455	462	488	511	527	536
Arkansas-White-Red	139	150	180	220	230	275	280	295	309	319	324
Texas-Gulf	16	89	110	140	190	227	231	244	255	263	268
Rio Grande	13	68	36	37	26	31	32	33	35	36	37
Upper Colorado	7	10	17	14	22	26	27	28	30	30	31
Lower Colorado	12	16	28	47	11	13	13	14	15	15	16
Great Basin	19	16	21	20	17	20	21	22	23	24	24
Pacific Northwest	55	55	47	47	49	59	60	63	66	68	69
California	66	45	50	54	47	56	57	60	63	65	66
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	2	3	7	5	5	6	6	6	7	7	7
Caribbean	4	6	8	9	7	8	8	9	9	9	9
U.S. Total	1437	1621	1713	1951	1901	2276	2311	2442	2555	2635	2681
Forest Service region											
Northern	65	74	61	67	60	98	100	105	110	114	116
Rocky Mountain	196	251	304	307	314	271	275	291	304	314	319
Southwestern	22	78	. 71	86	18	59	60	63	66	68	69
Intermountain	32	36	39	38	38	96	98	103	108	112	114
Pacific Southwest	68	47	56	59	51	157	160	169	176	182	185
Pacific Northwest	35	35	26	25	29	50	51	54	56	58	59
Southern	416	472	540	680	769	911	925	977	1022	1054	1073
Eastern	603	628	614	689	623	633	643	680	711	733	746
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Consumption	1437	1621	1713	1951	1901	2276	2311	2442	2555	2635	2681

Source: Data for 1960 through 1980 from U.S. Geological Survey Circulars. Data for 1985 from preliminary unpublished estimates furnished by the U.S. Geological Survey. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Figure A.1--Water resources regions

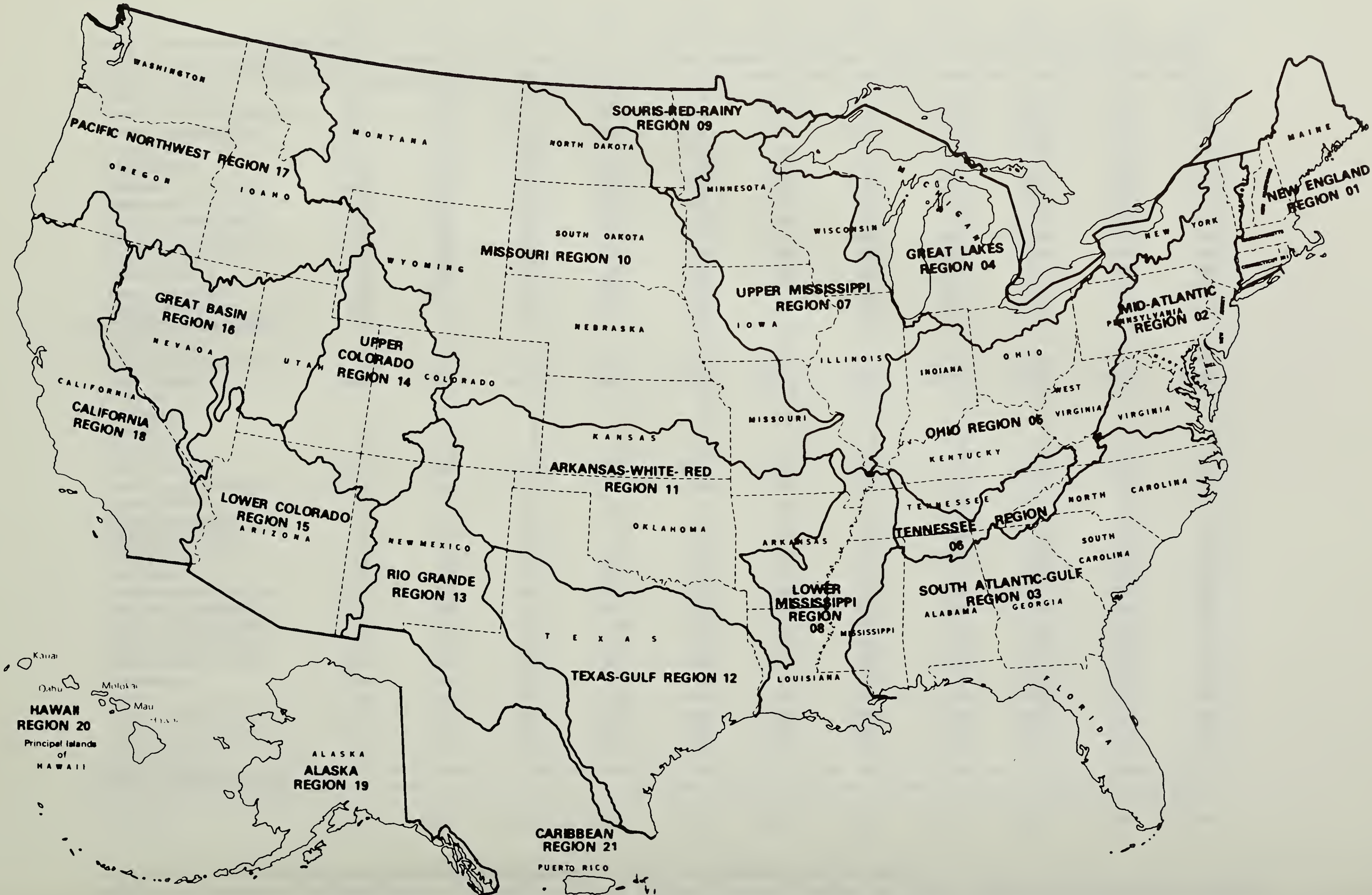


Figure A.2--Assessment and Forest Service regions

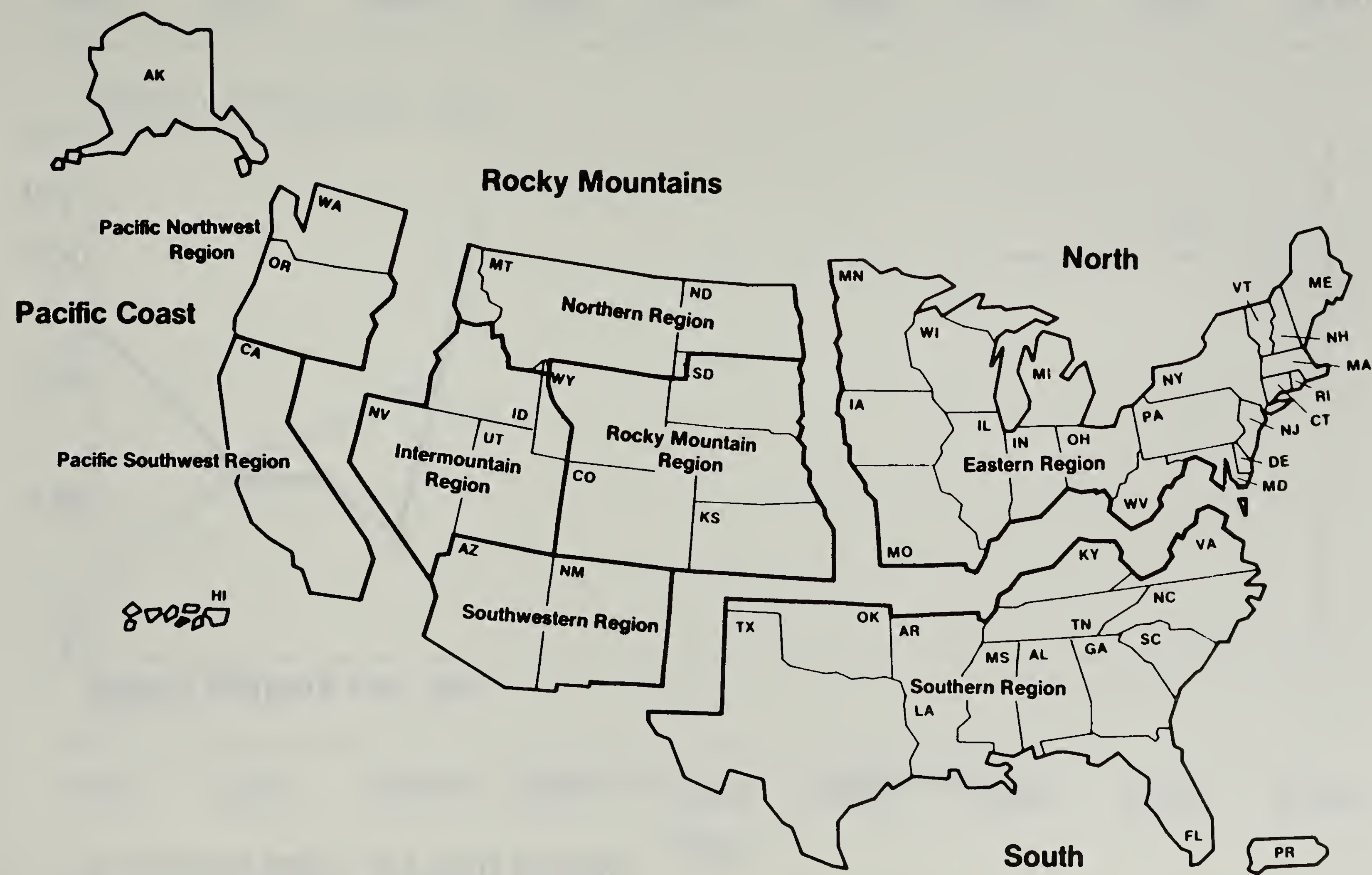
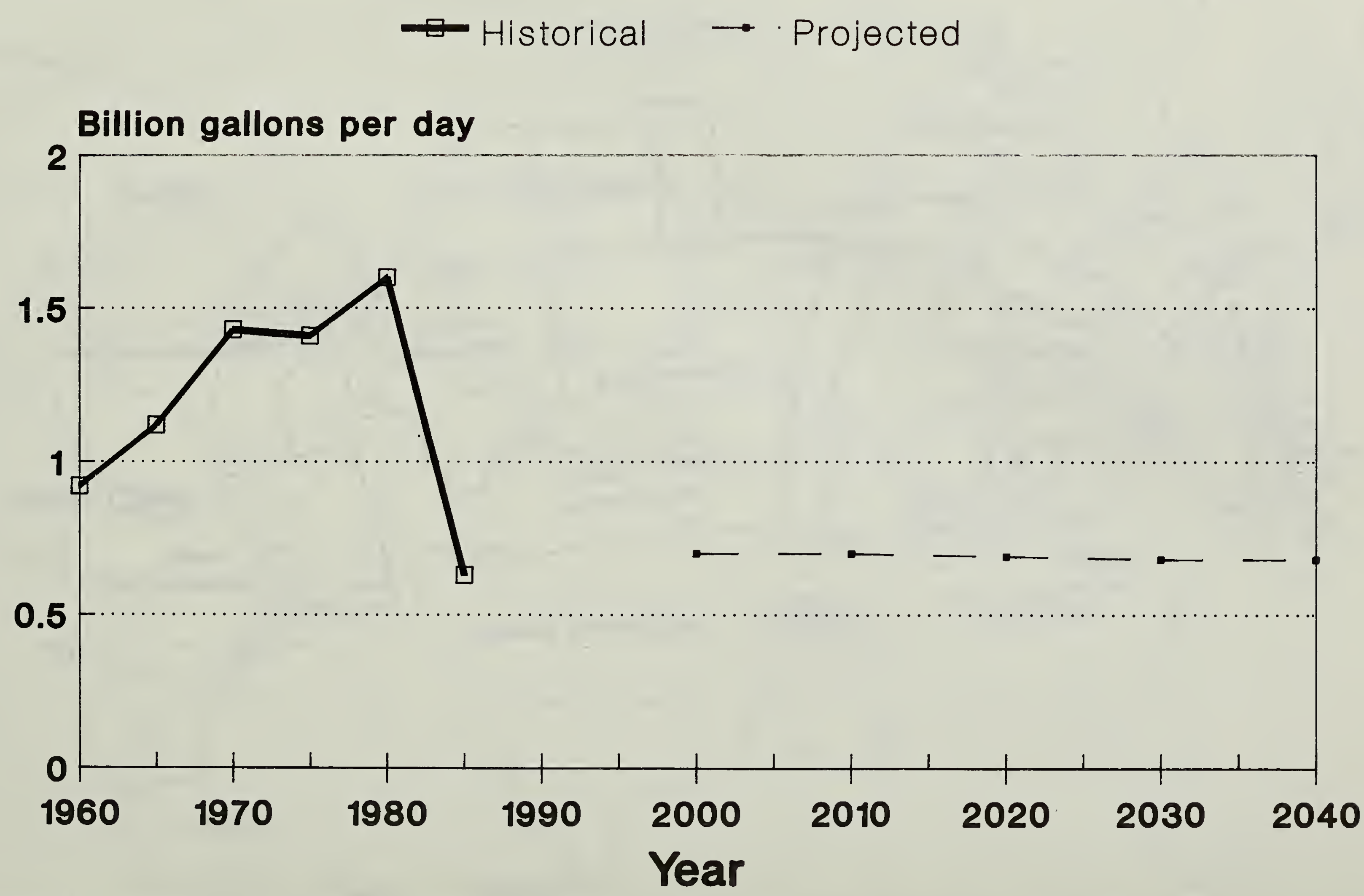
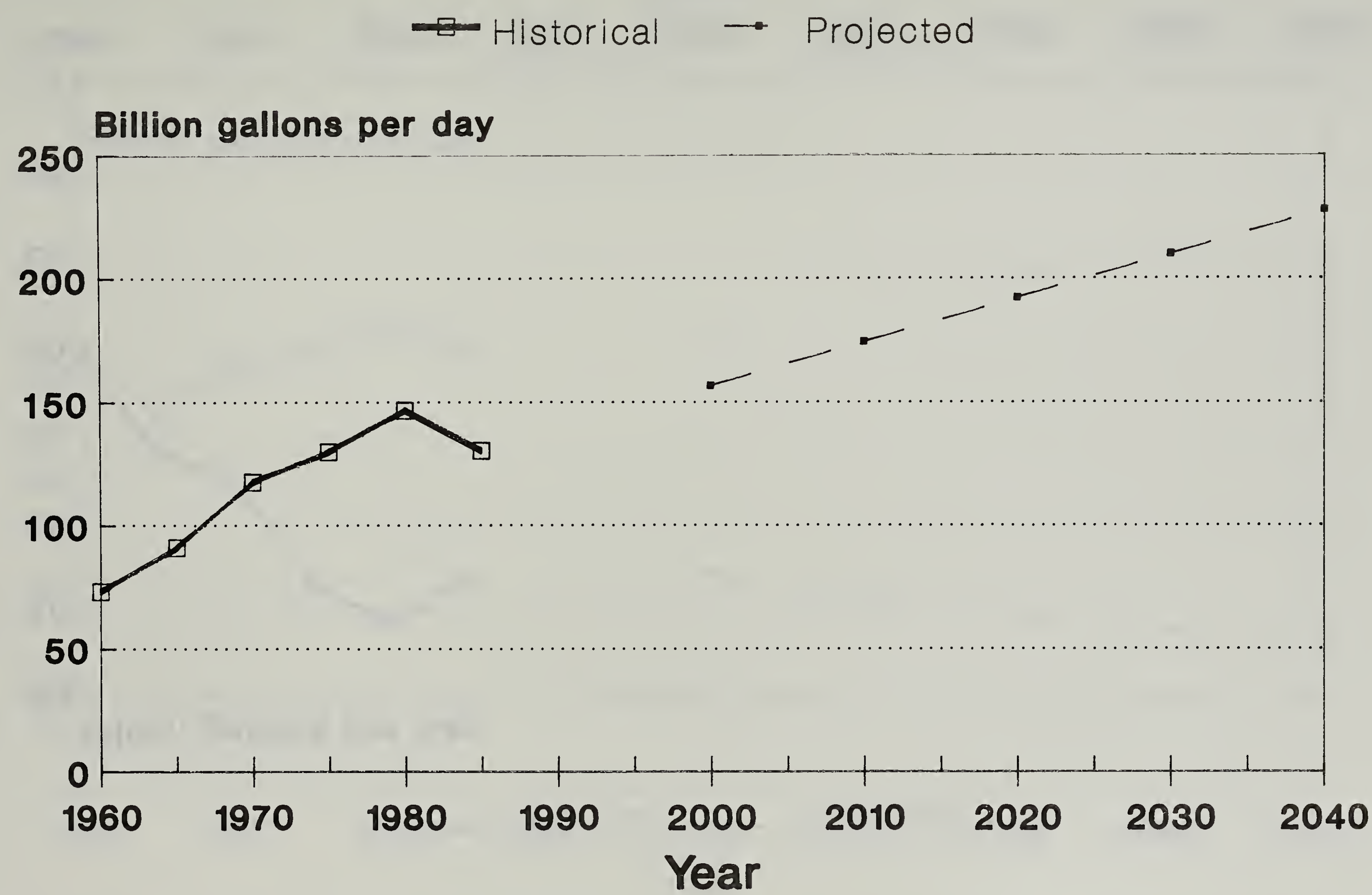


Figure A.3--Thermoelectric steam cooling, total fresh groundwater withdrawals



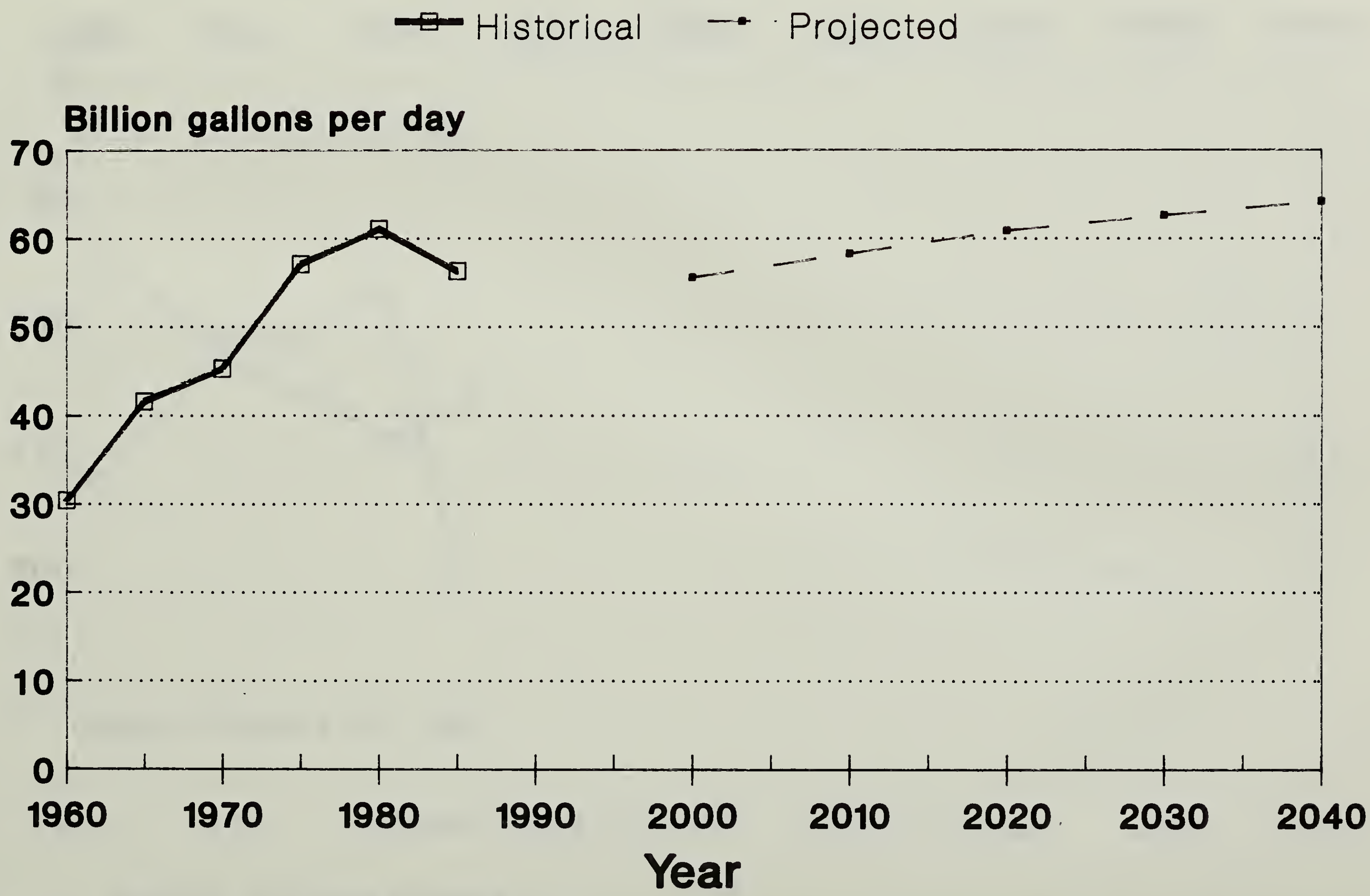
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.4--Thermoelectric steam cooling, fresh surface water withdrawals



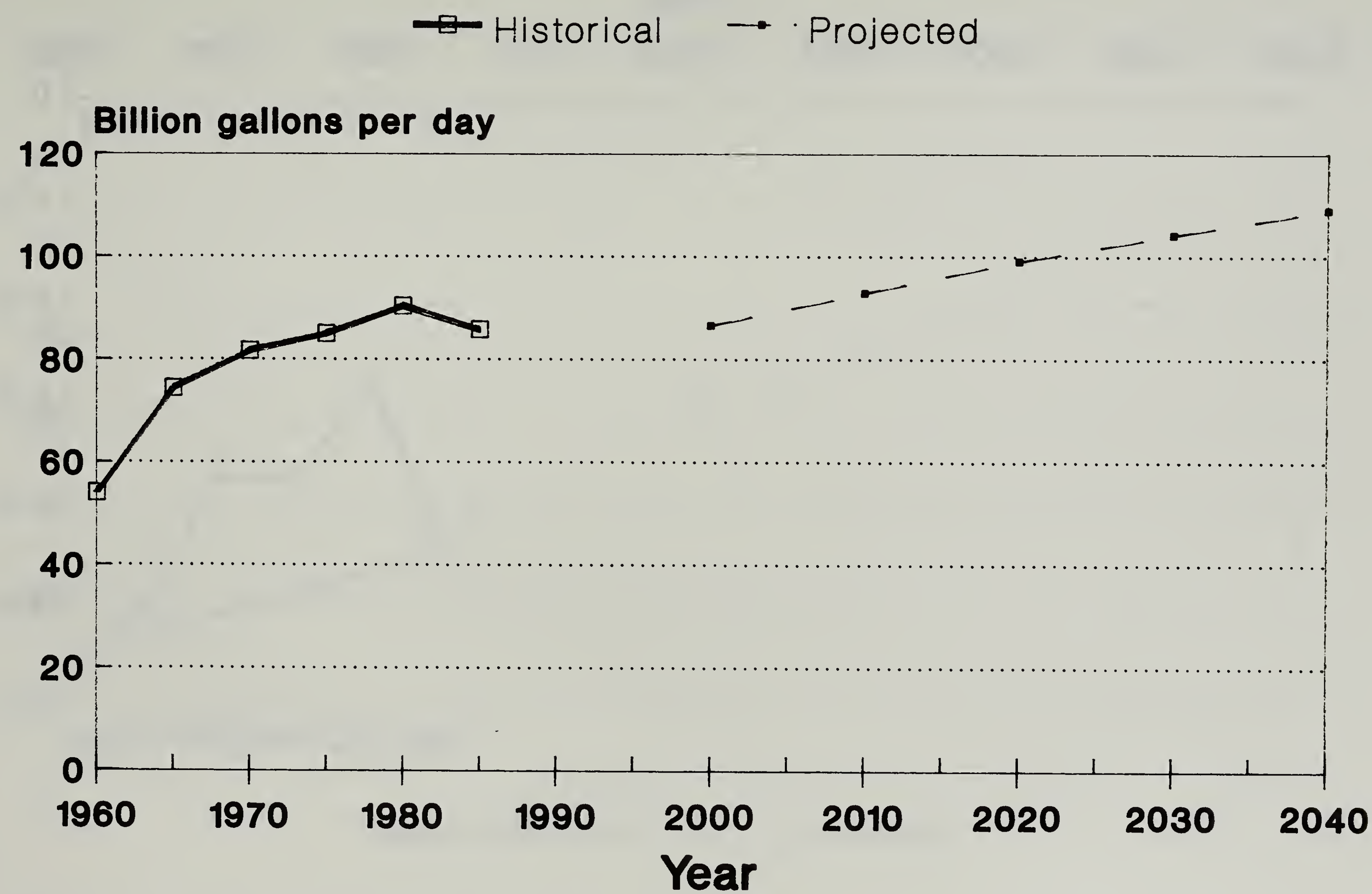
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.5--Irrigation, fresh groundwater withdrawals



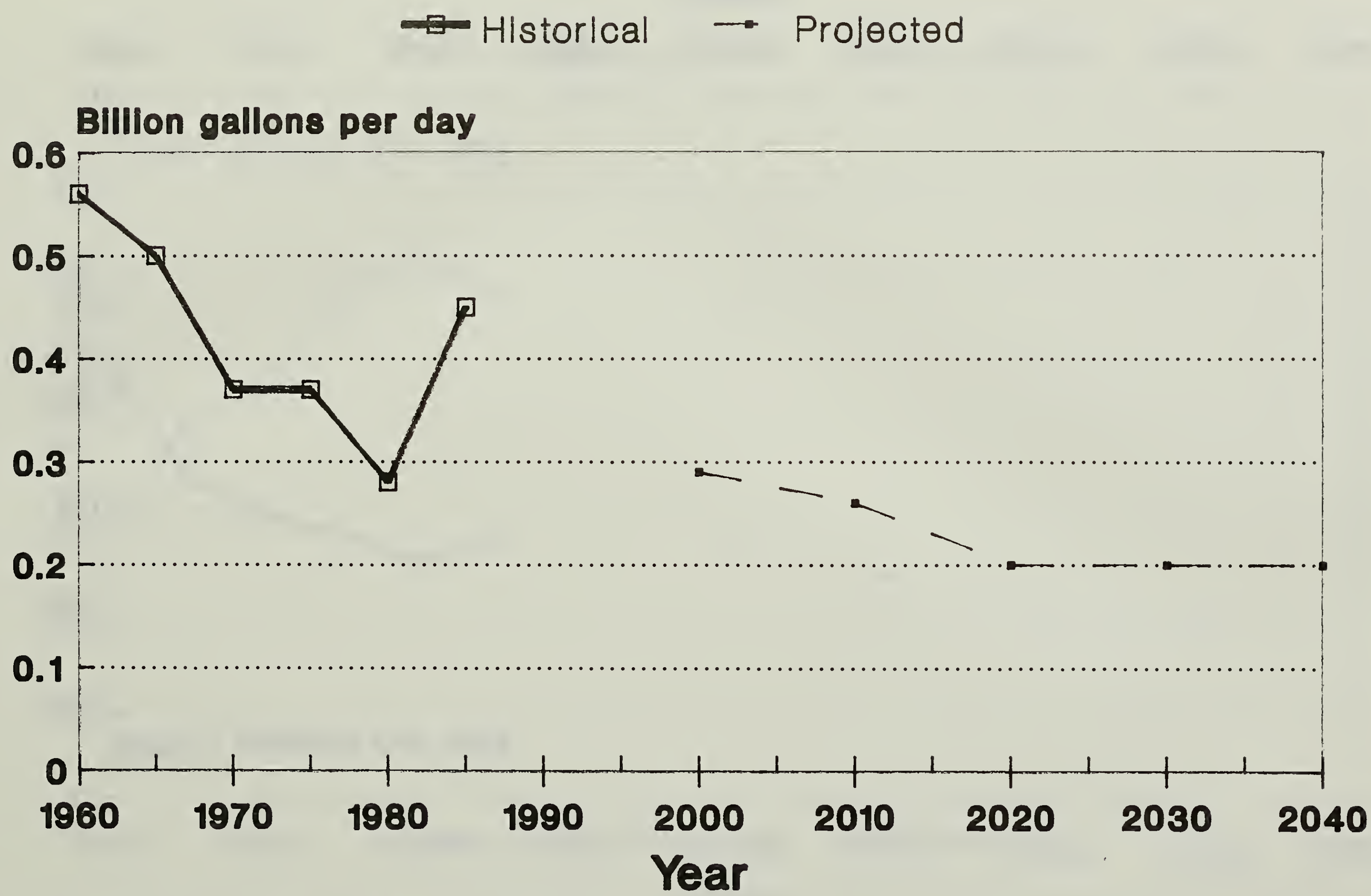
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.6--Irrigation, fresh surface water withdrawals



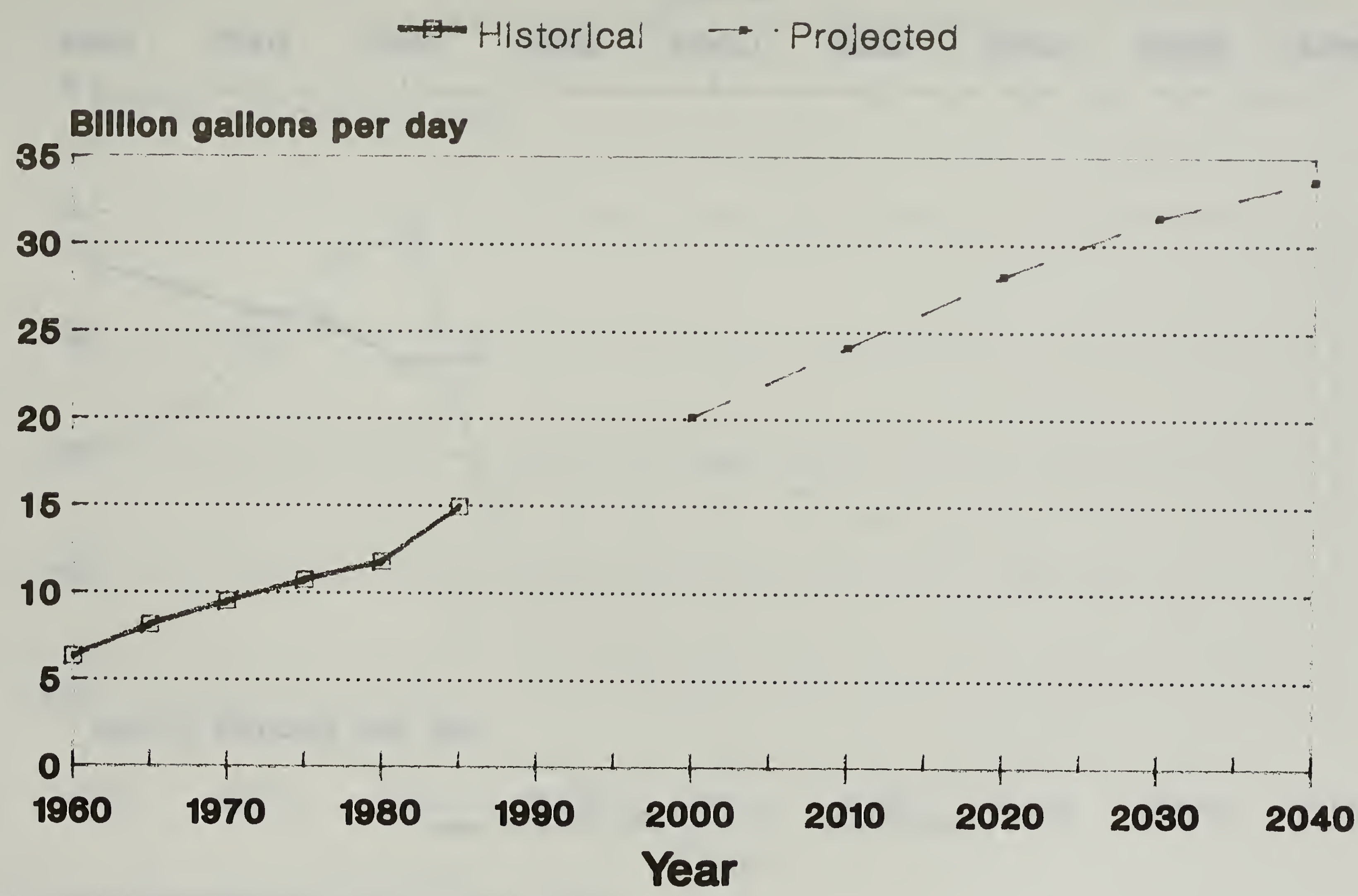
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.7--Irrigation, wastewater withdrawals



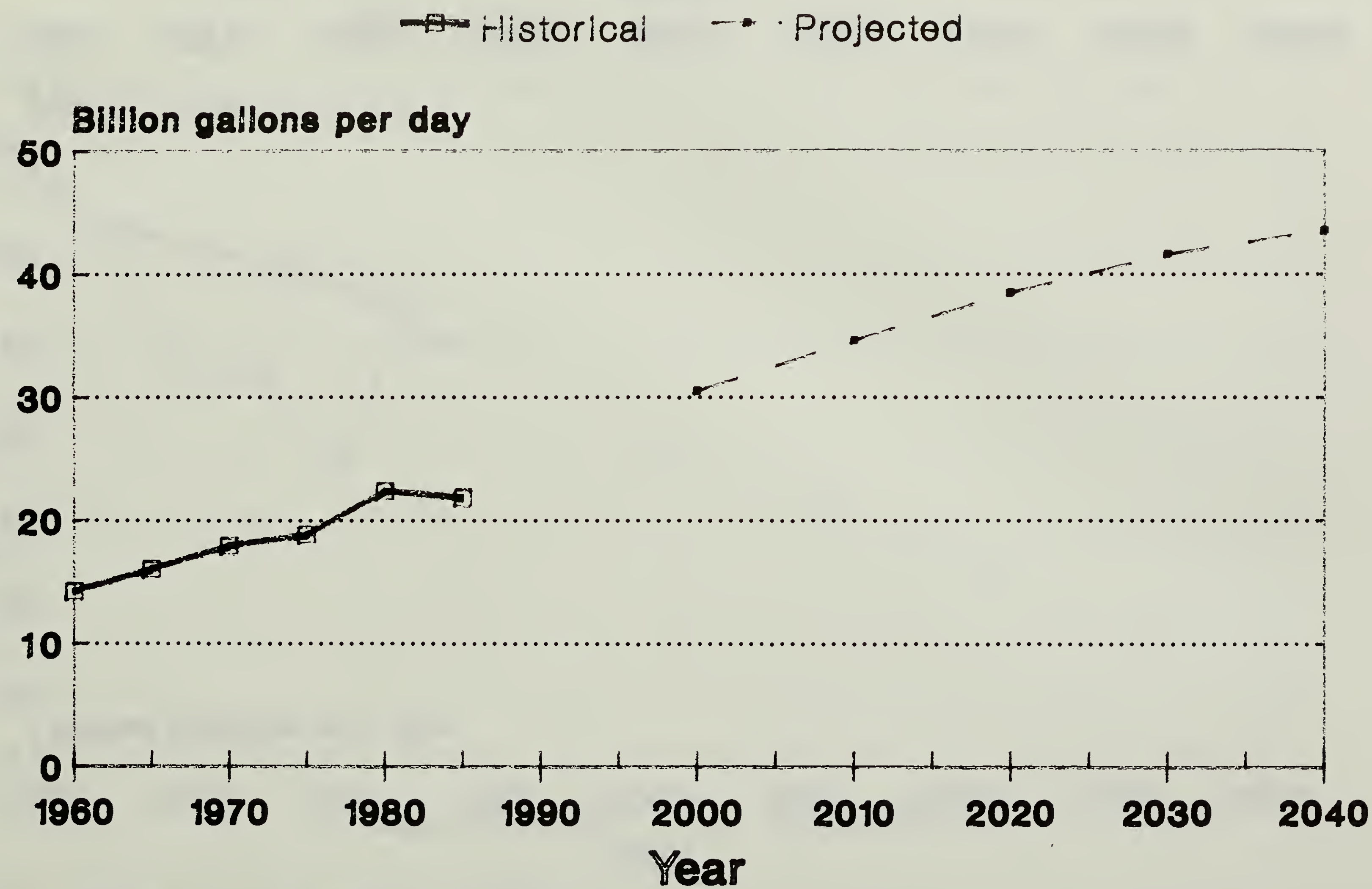
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.8--Municipal supplies, total groundwater withdrawals



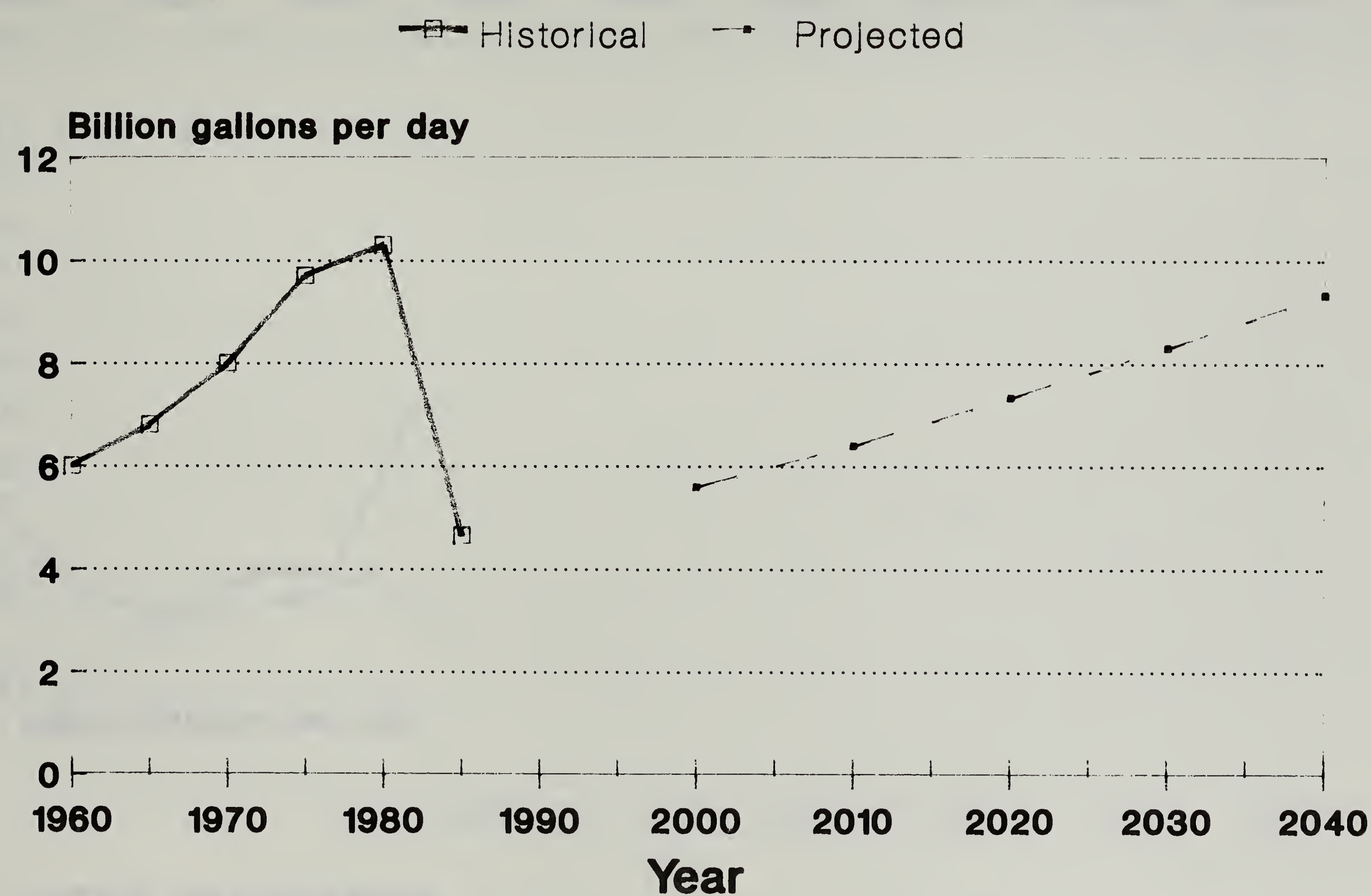
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.9--Municipal supplies, total surface water withdrawals



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.10--Industrial self-supplied water, total groundwater withdrawals



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.11--Industrial self-supplied water, total surface water withdrawals

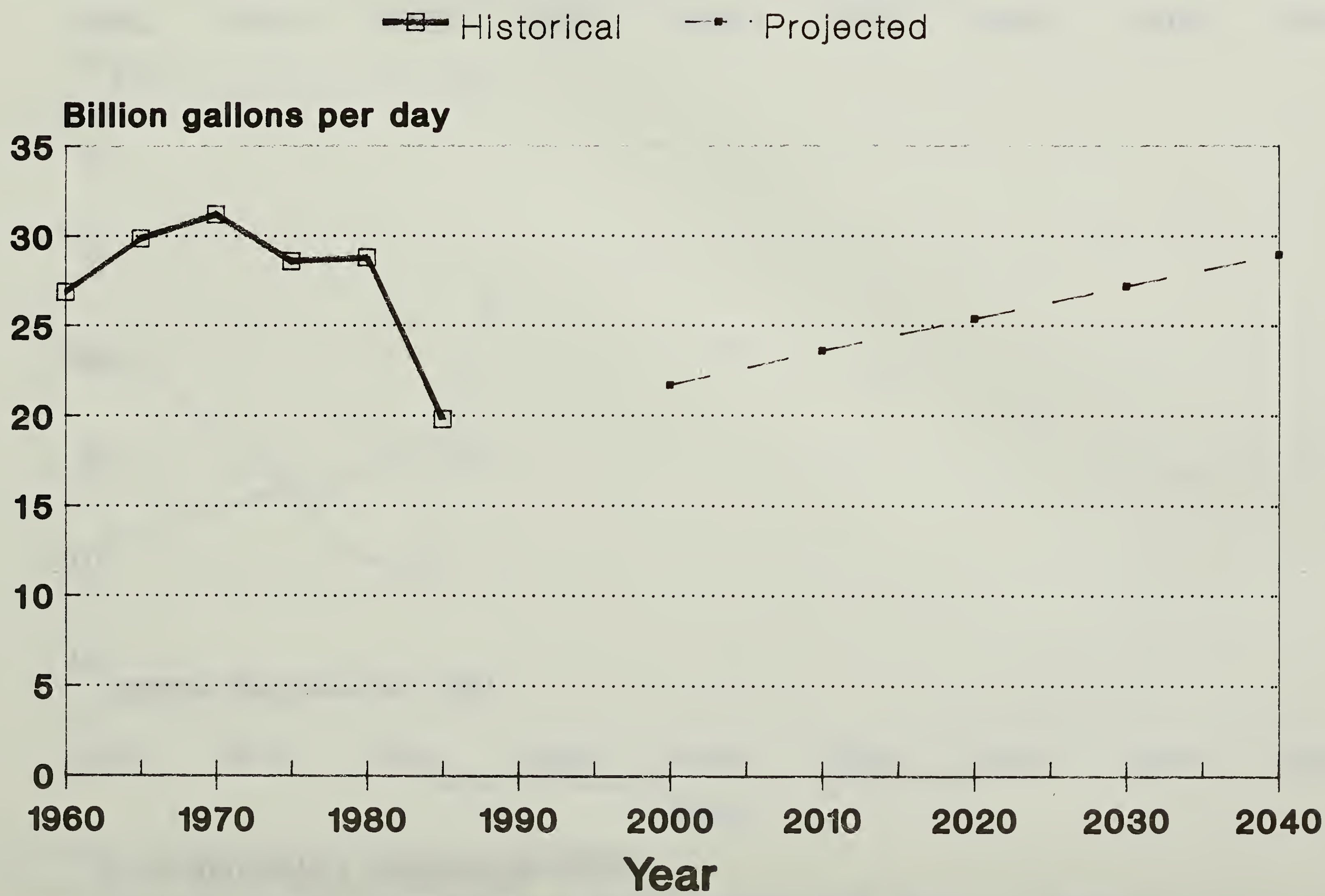
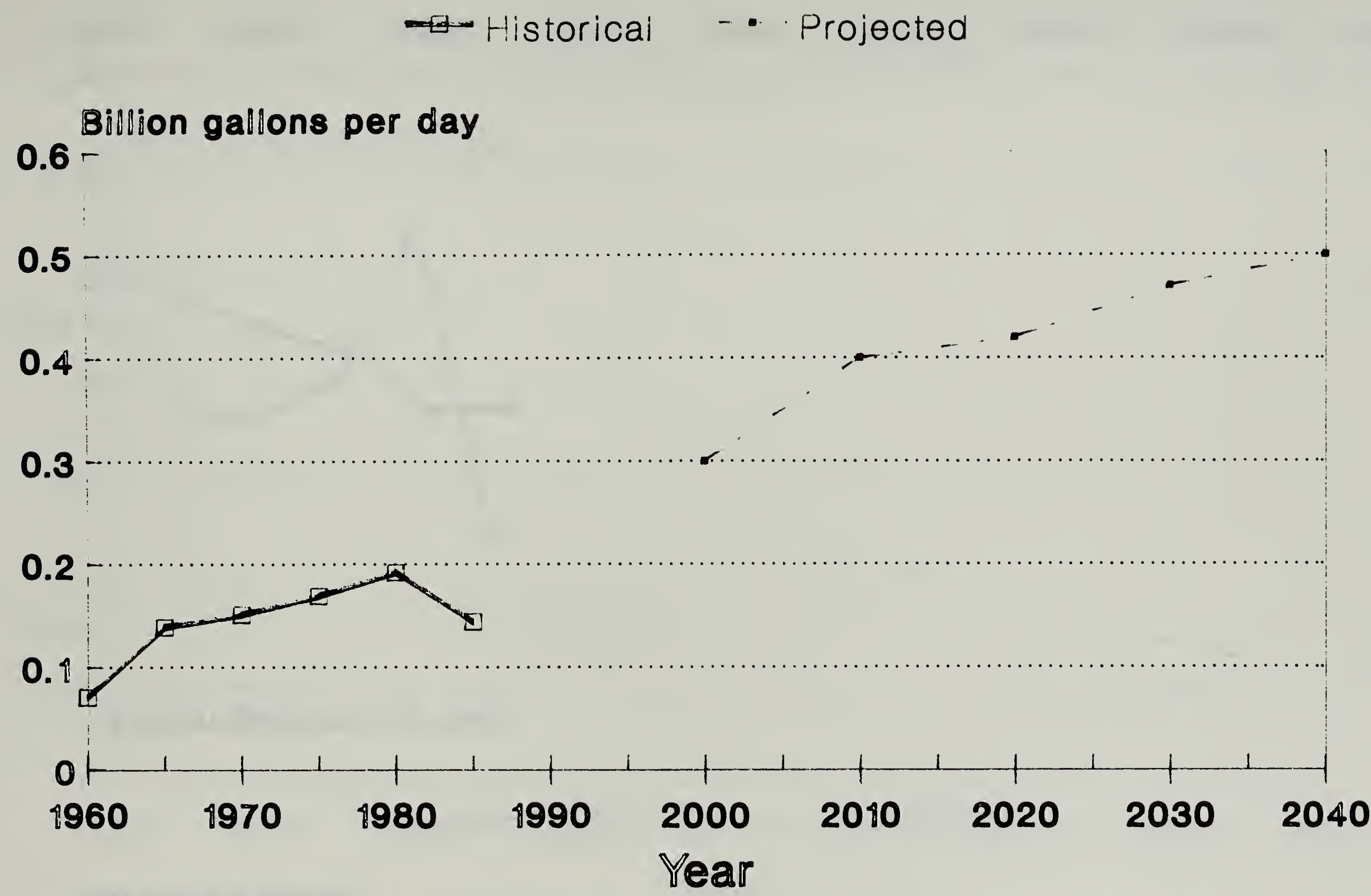
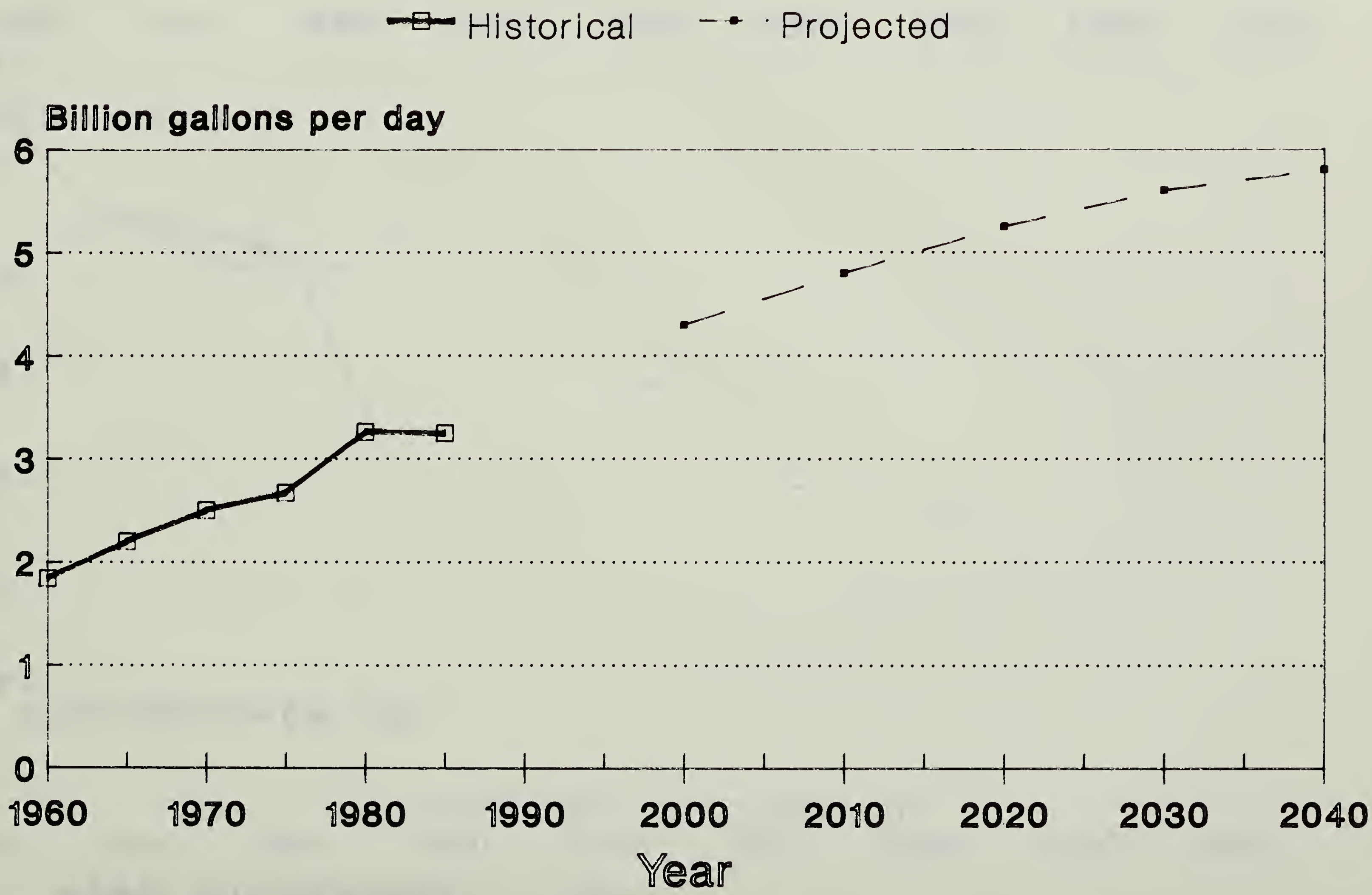


Figure A.12--Industrial self-supplied water, total waste-water withdrawals



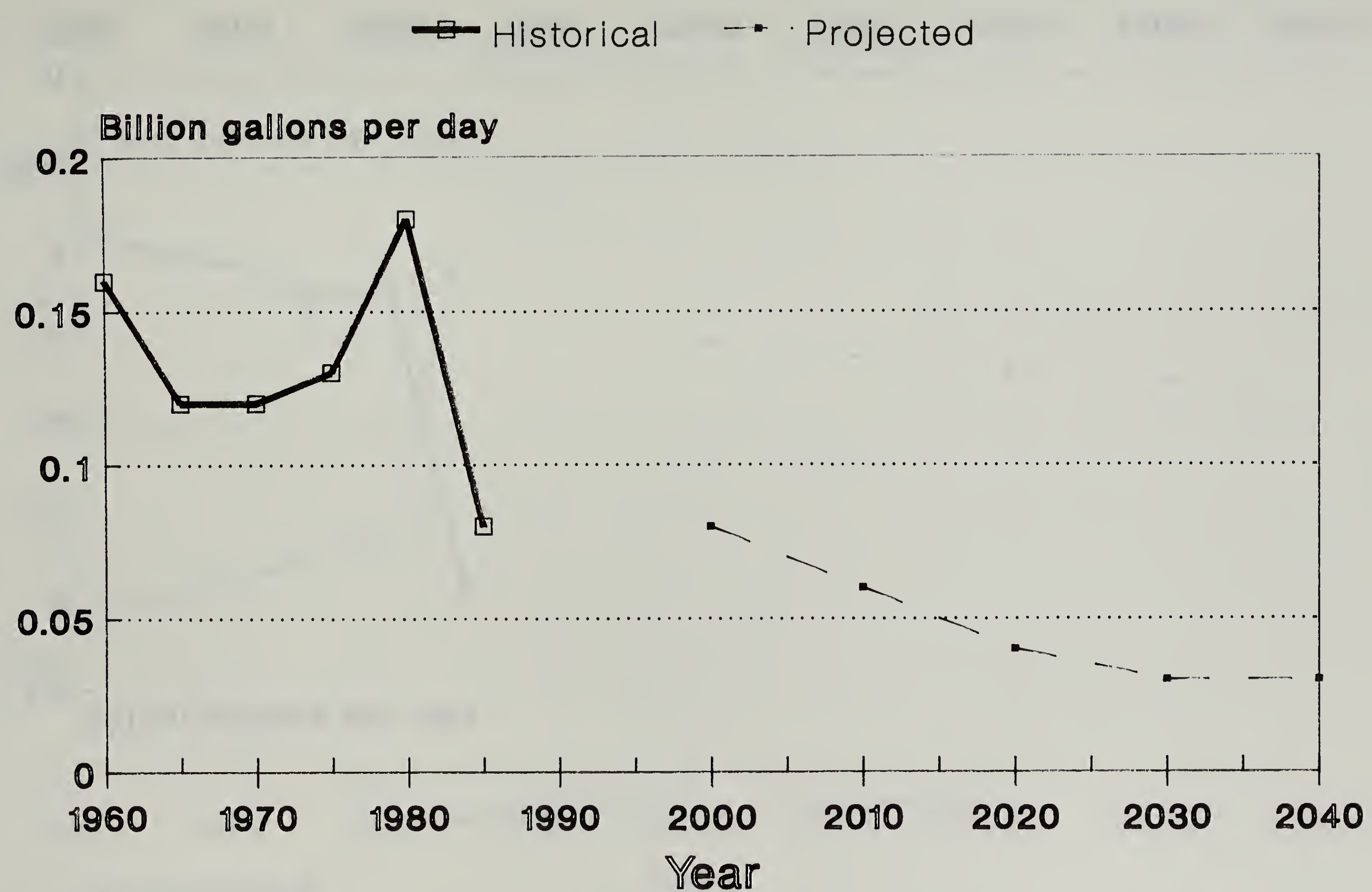
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.13--Domestic self-supplied water, total groundwater withdrawals



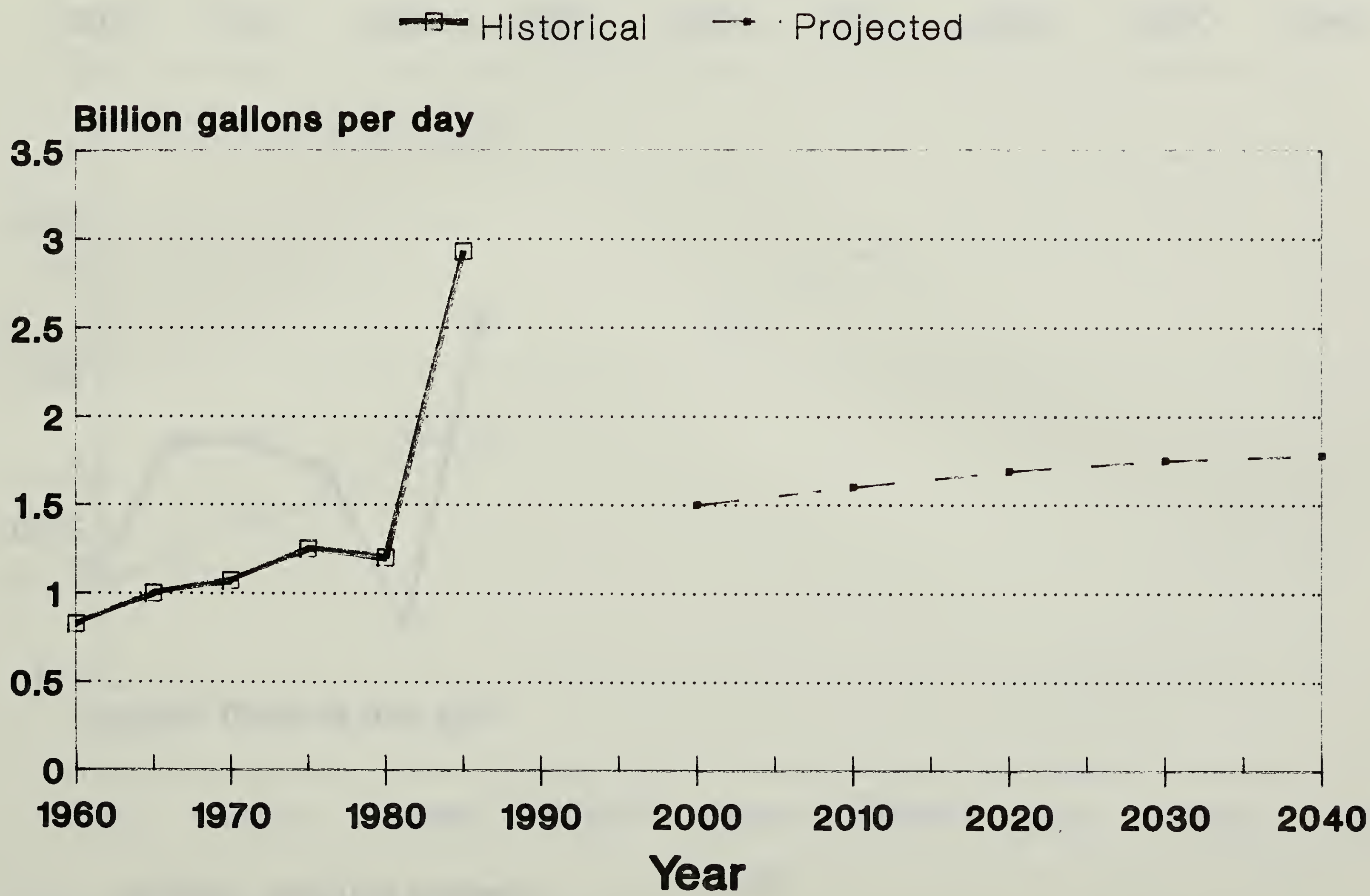
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.14--Domestic self-supplied water, total surface water withdrawals



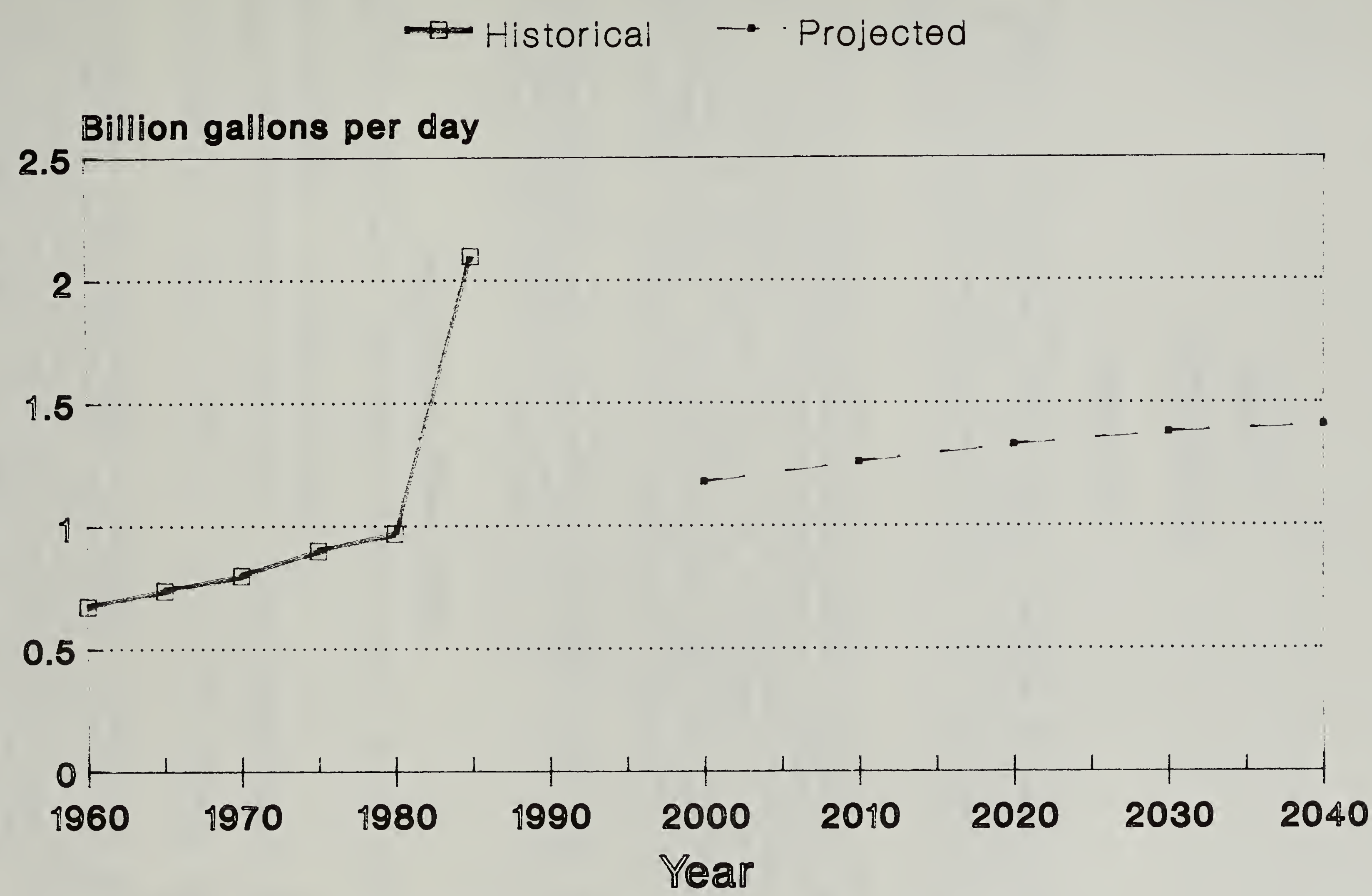
SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.15--Livestock watering, total groundwater withdrawals



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Figure A.16--Livestock watering, total surface withdrawals



SOURCE: Historical numbers from USGS Circulars. Projections by RPA Staff.

Appendix B

DEMAND EQUATIONS

Introduction

The demand equations were estimated using the 1987 release of BMDP for the Personal Computer. The personal computer version executes the same routines outlined by Dixon and others (1985). The stepwise regression routine was used to explore possible independent variables, table 2.4, for each dependent variable and transformation. Further analyses were performed using multiple linear regression.

Several different curve forms were tested for fit against the data. The prior assumption was that a logarithmic curve form was the most appropriate, given the emphasis on recycling and conservation engendered by legislation of the early 1970s. Semilogarithmic ($Y = \ln a + b \ln X$) and double logarithmic ($\ln Y = \ln a + b \ln X$; shown below as $\exp[c + b \ln x]$ where $c = \ln a$) curve forms were explored in preference to linear forms. The BMDP Data Manager for the Personal computer release (Engelman and others 1986) was used to perform the natural logarithm transformations of dependent and independent variables.

Unless otherwise specified, the F-statistics listed are for equations with a single explanatory variable and a time series of six data points (1960 to 1985 inclusive). The critical values for $F_{1,5}$ are 4.06, 6.61, and 16.3 for 10 percent, 5 percent, and 1 percent, respectively.

Thermoelectric Steam Cooling

Total freshwater withdrawals = $\exp[7.6658 + 0.5656 \ln \text{kWh}]$ $R^2=.93$ $F=51.6$

Groundwater withdrawals = No significant equations

Fresh surface water withdrawals = $\exp[7.6241 + 0.5701 \ln \text{kWh}]$ $R^2=.94$ $F=60.0$

Freshwater consumption = $-10642 - 3.2887$ kWh + 182.446 civilian labor force
$R^2=.98$ $F=91.2$

Because no significant equations emerged for groundwater withdrawals, the demand for fresh groundwater withdrawals was estimated as the difference between total freshwater withdrawals and fresh surface water withdrawals. Saline surface water (oceans and estuaries) is an alternative source of water for thermoelectric steam cooling. But because those utilities using groundwater tend to be located in arid areas far removed from coastal sites

where saline surface sources are available, saline surface sources were ignored for purposes of estimating groundwater withdrawals.

Billion kWh of power generated was selected as the best independent variable for projecting steam cooling withdrawals and consumption. The double exponential form suggests that conservation and recycling will continue to grow, but at a decreasing rate. Billion kWh were projected based upon the GNP relationships identified by the U.S. Department of Energy and the GNP projections from the basic assumptions for this Assessment.

Irrigation

Total freshwater withdrawals = -227076 + 50465.68 ln kWh R^2=.88 F=30.2

Groundwater withdrawals = -94490 + 20168.35 ln kWh R^2=.66 F=7.9

Fresh surface water withdrawals = -133814 +30414.04 ln kWh R^2=.94 F=67.3

Wastewater withdrawals = 1736 - 186.71 ln kWh R^2=57.8 F=5.5

Freshwater consumption = -84411 + 22194.83 ln kWh R^2=.79 F=14.8

The wastewater withdrawals equation has an F-statistic that is significant at the 7 percent level. Because wastewater withdrawals only represent two-tenths of one percent of the total demand for irrigation water in 1985, this level of significance was judged acceptable for projecting irrigation withdrawals. No other form or independent variable gave better results.

Billion kWh was selected as the most relevant independent variable to explain irrigation withdrawals and consumption. Electricity is the primary energy source used to pump water from aquifers and surface sources and pressurize sprinkler water delivery systems.

Municipal Supplies

Total freshwater withdrawals = exp[-1.1803 + 2.138 ln population] R^2=.987 F=235.4

Groundwater withdrawals = exp[-5.1671 + 2.6840 ln population] R^2=.976 F=120.9

Fresh surface water withdrawals = exp[-0.0643 + 1.8497 ln population] R^2=.971 F=98.9

Freshwater consumption = -76821 + 15504.6 ln population R^2=.95 F=72.8

Population is the most relevant independent variable for explaining changes in municipal withdrawals and consumption. The municipal supplies also serve some commercial and industrial facilities, but usage by these firms is largely for people-related purposes so population growth remains relevant.

Industrial Self-supplied Water Use

GNP was expected to be the most relevant independent variable for projecting industrial self-supplied water use. But regression equations could not be developed with GNP nor any other independent variable in the data set that explained a significant portion of the variation in industrial self-supplied water withdrawals. Although GNP continued to grow at nearly the same rate as during the 1960s and 1970s, water pollution legislation and policy changes forced changes in withdrawals independent of the continued growth in GNP. The change in withdrawals was so abrupt and happened so recently that statistically defensible projections of industrial self-supplied use cannot yet be made. Consequently, projections were based upon simple time trends. The projections assume that a major adjustment in water use occurred in the 1980s, but that industrial self-supplied use will soon resume growing at about 95 percent of the annual rate of growth between 1960 and 1980--roughly 275mgd/year. This total rate of increase was disaggregated into 130 mgd/year in fresh surface water withdrawals, 90 mgd/year in groundwater withdrawals, and 54 mgd/year in wastewater withdrawals. The consumption equation, however, explains virtually all the variation in consumption and is highly significant:

Freshwater consumption = -21953 + 3335.4 ln GNP R^2=.989 F=374.7

Domestic Self-supplied Water Use

Total freshwater withdrawals = -2535 + 28.089 population R^2=.94 F=58.8

Groundwater withdrawals = -2838 + 25.916 population R^2=.96 F=104.

Fresh surface water withdrawals = no significant independent variable

Population was also selected as the most relevant independent variable for explaining variation in rural domestic water withdrawals. The statistical analysis of fresh surface water withdrawals produced no significant independent variables, merely a highly significant intercept term. Consequently, surface water withdrawal estimates were computed as the difference between the projected total and projected groundwater withdrawals.

Statistical analyses of freshwater consumption yielded no significant equations. R-squared for the equations tested varied between .03 and .35 and the best F-statistic had a probability value of about .08. Thus, a combination of time and population trends were used to project freshwater consumption, Figure 2.21.

Livestock Watering Use

Total freshwater withdrawals = -12200 + 2650 ln population R^2=.96 F=72.8

Groundwater withdrawals = -6619 + 1446.32 ln population R^2=.87 F=19.53

Fresh surface water withdrawals = -5581 + 1203.68 ln population R^2=.95 F=53.6

Freshwater consumption = -8467 + 1919.02 ln population R^2=.90 F=26.5

The 1985 livestock withdrawal estimates are significantly different than the previous years, Figure 2.24. Consequently, the 1985 data were excluded from the equation estimation process.

Population was selected as the most relevant independent variable because it stands as a surrogate for red meat consumption. The basic assumption for red meat consumption for this Assessment was to hold percapita red meat consumption constant over the projection period. A similar case could be made for assuming percapita consumption of dairy products is constant over the projection period. Because percapita consumptions are constant, growth in the demand for animal products becomes a function of population.

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Appendix C

SUMMARY OF STATE WATER QUALITY LAWS AFFECTING FORESTRY OPERATIONS[1]

Table No.	Contents	Page Numbers
C.1	Significant features of water quality legislation in the South	C-1 to C-7
C.2	Significant features of water quality legislation in the North	C-8 to C-33
C.3	Significant features of water quality legislation in the Rocky Mountain region	C-34 to C-50
C.4	Significant features of water quality legislation in the Pacific Coast region.	C-51 to C-66

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Table C.1--Significant features of water quality legislation in the South

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Alabama	Water Pollution Control Act. Ala. Code, Sec. 22-22-1 to 14. Enacted 1971; amended 1973, 1979, 1982.	Alabama Water Improvement Commission.	Pollutants harmful to fish or wildlife, or constituting a public hazard are subject to regulation. Commission granted permit issuing authority for control of discharges of such pollutants into waterways. Commission may issue cease-and-desist orders and commence civil actions to enjoin actual or threatened violations.	Civil: $100 to $10,000 fine per day of violation of a Commission rule or order. Criminal: $2,500 to $25,000 per day of violation and/or imprisonment for up to one year. Penalty may be doubled on second conviction. Payment of costs of damage, and restocking of fish and wildlife.	No reference to silvicultural discharges or wastes from timber transport or harvesting. Law probably applicable to nonpoint pollution if damage to fish or wildlife clearly attributable.	Coastal Preservation Act (Ala. Code, Sec. 9-7-14 to 9-7-22) Activities permitted include planting and harvesting of trees including normal road construction.
Arkansas	Water and Air Pollution Control Act. Ark. Stat. Ann. Sec. 82-1901 to 1991. Enacted 1949; amended 15 times, 1953 to 1985.	Department of Pollution Control and Ecology (under authority of Arkansas Pollution Control Commission).	Department given broad authority to issue permits and orders, and to promulgate rules and standards, with respect to prohibited pollutants. Department can initiate civil action to force compliance with orders and standards.	Civil: up to $5,000 fine per day of violation plus payment of administrative expenses and damages. Criminal: violation considered misdemeanor. Up to $10,000 and/or one year in prison per day of violation.	Definition of pollution and Department's vested powers sufficiently broad to apply to nonpoint sources. Prohibited pollutants include decayed wood, sawdust, shavings, bark and sand. One member of the State Pollution Control Commission must be from the State Forestry Commission.	Stream Obstruction Statutes (Ark. Stat. Ann. Sec. 41-4052 and Sec. 41-4066 to 41-4067) prohibit obstructing any improved drainage project or any natural drain with trees, tree tops or limbs. Tree Removal in Riparian Areas (Sec. 41-4068 to 41-4069) prohibits removal of trees growing below normal high water mark of any navigable river or stream.

Table C.1--Significant features of water quality legislation in the South (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Florida	Air and Water Pollution Control Act. Fla. Stat. Ann. Sec. 403.011 to 403.291. Enacted 1971; amended 1972, 1974,1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985.	Department of Environmental Regulation.	Department given broad powers to develop water pollution abatement programs. Department must issue permits for all pollutant discharges pursuant to federal administrative requirements. Department may issue orders and seek injunctive relief against violations. Exception: Water owned entirely by one person excluded from Department control unless affecting other properties or water.	Civil: up to $10,000 fine per day of violation. Criminal: Violation considered first degree misdemeanor. Fine of $2,500 to $25,000 and/or one year in prison per day of violation. False statement or misrepresentation: up to $10,000 and/or six months in prison. Department can initiate civil action to establish liability and recover damages, including those for fish mortality.	Powers granted to Department are sufficiently broad to include regulatory authority over nonpoint pollution from land management activities.	Warren Henderson Wetlands Protection Act of 1984 (Fla. Stat. Ann. T.29 Sec. 403.91 to 403.929) empowers Florida's five water management districts to regulate silvicultural activities which divert or impede normal water flow. Some districts require permits, others notification and/or merely compliance with standards.
Georgia	Water Quality Control Act. Ga. Code Ann. Chap. 12-5-20 to 12-5-53. Enacted 1971; amended 1972, 1974, 1977, 1978, 1982, 1983, 1986.	Division of Environmental Protection, within Department of Natural Resources (under authority of Georgia Water Quality Control Board).	Water Quality Control Board has broad authority to promulgate rules and regulations to control water pollution. Division of Environmental Protection can issue permits for both point and nonpoint discharges; can also issue stop orders. Statute applies to all waters except those entirely confined and retained on the property of a single ownership. All aspects of the program are to be consistent with the Federal Water Pollution Control Act.	Civil: up to $25,000 fine per day of violation. Criminal: violation considered misdemeanor. Fine of $2,500 to $25,000 per day of violation and/or one year in prison. Penalty doubled for repeated offense. False misrepresentation: felony; up to $10,000 and/or two years in prison. Assessment of civil liability for damages.	Division of Environmental Protection has explicit authority to issue permits for discharge of nonpoint pollutants. 1978 amendment to Water Quality Control Act provides for state administration of Federal Water Pollution Control Act Section 404 permit program.	

Table C.1--Significant features of water quality legislation in the South (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Kentucky	Environmental Protection Law. Ky., Rev. Stat., Sec. 224.005 to 224.997. Enacted 1972; amended 1974, 1978, 1980, 1982, 1984.	Bureau of Environmental Protection within the Department of Natural Resources and Environmental Protection.	Department has broad authority to issue water quality rules and regulations; and to issue discharge permits in accordance with Federal Water Pollution Control Act guidelines. Department may initiate court action against violations. Exceptions: exemptions may be granted for up to one year if discharge is not likely to have a measurable impact on water quality and/or compliance would produce undue hardship without equal or greater benefit to the public.	Civil: up to $10,000 fine per day of violation. Criminal: violation considered misdemeanor; fine of $1,000 to $15,000 and/or imprisonment for up to one year per day of violation. Payment of costs of damage, and restocking of fish and wildlife.	Legislative authority broad enough to cover nonpoint pollution at discretion of Department. Department required to monitor environment for more effective and efficient control practices.	Kentucky Wild Rivers Act (Ky. Rev. Stat., Sec. 146.200 to 146.350) permits only selective cutting of timber within boundaries of designated wild river areas. Stream Obstruction Statute (151.310 to 151.320) prohibits the deposit of any matter which disturbs the flow of water in streams without a permit.

Table C.1--Significant features of water quality legislation in the South (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Louisiana	Water Control Law. La. Rev. Stat. 30:1073 and 30:1091-1097. Enacted 1979; amended 1980, 1983, 1984 1987.	Department of Environmental Quality and the Office of Water Resources (OWR)	The OWR is empowered to develop a general water protection plan and to regulate and restrain the discharge of pollution into waters. The Department establishes standards and guidelines; promulgates rules and regulations; and issues permits for the control of water pollution. Commission may initiate civil liability action.	No penalties may be imposed for unintentional pollution in connection with production of agricultural products. Commission may recover civil damages. Violations: polluting waters with substance which is not likely to endanger human life or health is a misdemeanor; punishable by a fine of up to $25,000/day of violation and/or up to one year imprisonment. Polluting with a substance which could endanger human life or health is a felony punishable by a fine of up to $100,000/day and/or 10 years imprisonment. Civil penalties are up to $25,000/day of violation. Up to $50,000/day for failure to take corrective action after compliance order is issued.	Legislative authority broad enough to cover nonpoint pollution at discretion of Department. Specifically empowers the Department to develop a nonpoint source management program. Law includes a provision prohibiting persons engaged in logging operations from leaving trees or treetops in navigable waters. Administrative regulations exempt silvicultural operations from permit requirements.	State and Local Coastal Resources Management Act of 1978 (La. Rev. Stat., Sec. 49:213.1 to 49:13.22). Permits are not required for silvicultural activities when forest practices used consistently in the past are employed. An experimental or unconventional practice might require a permit. Natural and Scenic River System Act (Sec. 56:1841-1849.2) permits only selective cutting within 100 feet of scenic rivers. Requires removal of tree tops from rivers.

Table C.1--Significant features of water quality legislation in the South (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Missis-sippi	Air and Water Pollution Control Act. Miss. Code, Sec. 49-17-1 to 49-17-53. Enacted 1966; amended 1968, 1971, 1972, 1973, 1977, 1978, 1980, 1981, 1985.	Commission of Natural Resources under authority of Bureau of Pollution Control of Department of Natural Resources.	Commission empowered to develop standards and programs for prevention, abatement and control of water pollution. A separate permit board issues permits for the discharge of contaminants. Commission can issue cease-and-desist orders during an emergency.	Civil: up to $25,000 fine per day of violation. Criminal: $2,500 to $25,000 per day of violation. Commission can initiate civil action to recover actual damages.	Commission's powers are broad enough to be applied to nonpoint sources of pollution.	Stream Obstruction Law (Miss. Code Sec. 97-15-41) prohibits the felling of trees or leaving logs in excess of six inches in diameter or tree tops in a running stream.
North Carolina	Water and Air Resources Acts. N.C. Gen. Stat. Sec. 143-214. Enacted 1951; amended 1957, 1959, 1967, 1969, 1973, 1975, 1977, 1979, 1983, 1985.	Department of Natural Resources and Community Development under authority of Environmental Management Commission.	Commission has broad powers over water pollution, is authorized to issue permits for discharge of pollutants, and can issue orders directed at a violator after a hearing is held.	Civil: up to $10,000 fine per day of violation. Criminal: violation considered misdemeanor; fine of up to $15,000 per day of violation, not to exceed a total of $200,000 for each 30-day period, and/or imprisonment for up to six months. Commission can initiate civil action to recover actual damages.	Sawdust and wood shavings are listed as potential pollutants in the law. Nonpoint pollutants are covered under the statute's definition of water pollution which includes "alterations resulting from the concentration or increase of natural pollutants caused by man-related activities".	Stream Obstruction statutes (N.C. Gen. Stat., Sec. 77-13 and 77-14) prohibit the felling of any tree, or the leaving of slash, stumpage, sawdust, shavings, etc. in any stream so as to obstruct drainage.
Oklahoma	Pollution Control Coordinating Act. Okla. Stat. Title 82, Sec. 931 to 942. Enacted 1968; amended 1971, 1974, 1976, 1981, 1983. Pollution Remedies Law, Okla. Stat. Title 82, Sec. 926.1 to 926.13. Enacted 1972, amended 1981.	Water Resources Board under authority of Pollution Control Coordinating Board.	Department has executive authority over all state agencies administering pollution programs. Definition of pollution is broad and includes those substances potentially injurious to aesthetic sensibilities. Exception: law does not apply to waters entirely in one ownership unless affecting another's property or water.	Criminal: willful violation of any promulgated order is considered misdemeanor, punishable by maximum fine of $200 to $10,000 per day of violation and/or up to six months imprisonment. Civil penalty: up to $10,000. Civil liability for damages lies with those responsible for violation.	Broad authority granted to Department of Pollution Control and Water Resources Board covers nonpoint source pollution.	

Table C.1--Significant features of water quality legislation in the South (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
South Carolina	Pollution Control Act. Code Laws S.C. Title 48, Sec. 48-1-10 to 48-1-350. Enacted 1971; amended 1973, 1974, 1975, 1978, 1980.	Department of Health and Environmental Control.	Department charged with responsibility of administering all state programs under Federal Water Pollution Control Act. Department has permit issuing authority, and can promulgate rules and regulations. Can issue orders and initiate legal proceedings to force compliance. Exception: no civil or criminal liabilities to be imposed for violations caused by acts of God, war, strike, riot, or catastrophe.	Civil: fine not to exceed $10,000 per day of violation. Criminal: Violation considered misdemeanor; punishable by fine of from $500 to $25,000 per day of violation and/or imprisonment for up to two years. Department can initiate civil liability proceedings to recover costs of damage.	The statute addresses the term "pollutant" in its broadest sense, thereby presumably covering all nonpoint sources. Statute specifically lists decayed wood, sawdust, shavings, bark and sand as potential pollutants.	Stream Obstruction statute (Code Laws S.C. Title 49, Sec. 1-20) prohibits streambank damage or obstructing waterways with felled timber. Scenic Rivers Act (Title 51, Sec. 5-120) prohibits timber harvesting within designated distances of Class 1 streams on state controlled lands. Stream Cleaning Act (Title 49, Sec. 1-30) requires landowners to clean out the streams adjacent to their properties twice a year and to keep them free of obstructions which would interrupt the flow of sand and water.
Tennessee	Water Quality Control Act. Tenn. Code Ann. Sec. 69-3-101 to 69-3-121. Enacted 1971; amended 1972, 1973, 1977, 1979, 1981, 1982, 1984, 1985.	Division of Water Quality Control (within Department of Public Health) under authority of Water Quality Control Board.	Department of Public Health has broad authority to control water pollution, through regulations issued by Division of Water Quality Control. Nonpoint pollution caused by agricultural and forestry activities are exempt from regulation. Department of Public Health may issue cease-and-desist orders, and order corrective action.	Civil: up to $10,000 fine per day of violation. Criminal: violation is considered misdemeanor; punishable by fine of $50 to $25,000 per day of violation. Willful noncompliance, falsification of records, or misrepresentation considered felony and punishable by fine up to $25,000 and/or two years imprisonment. Department of Public Health can assess civil damages.	Pollution caused by agricultural or forestry activities subject to regulation only if point source involved. Statute specifically lists decayed wood, sawdust, silt, shavings, bark and rock as potential pollutants (subject to regulation if point source).	Scenic Rivers Act of 1968 (Tenn. Code Ann. Sec. 11-13-102 to 11-13-117). Commercial timber harvest is prohibited in protected river areas within conservation or public use easement.

Table C.1--Significant features of water quality legislation in the South (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Texas	Water Quality Act. Texas Code Ann., Water Code, Title 2, Sec. 5.001 to 5.357 and 26.001 to 26.225. Enacted in 1977; amended 1981, 1985.	State Water Commission and State Water Development Board under the Department of Water Resources.	Water Commission may grant authority to local governments to issue permits for discharge of waste into water. Commission itself can also issue rules, regulations and orders to control water quality.	Civil: $50 to $10,000 fine per day of violation. Criminal: $10 to $10,000 per day for violation of a rule or regulation.	The statute specifically covers agricultural waste, presumably including residues from forestry activities. Statute specifically lists decayed wood; sawdust; shavings; bark; runoff from irrigation; and rainfall runoff from cultivated or uncultivated rangeland, pastureland and farmland that may impair water quality.	Stream Obstruction Act (Texas Code Ann. Sec. 5.096) prohibits obstruction of navigable streams by cutting and felling of trees.
Virginia	Water Control Law. Code Va., Sec. 62.1-44.2 to 62.1-44.42. Enacted 1973; amended 1974, 1976, 1977, 1978, 1980, 1981, 1984, 1985, 1986.	Water Control Board.	After conducting a hearing, Board can issue special order to prohibit pollution, and also seek injunctive relief against violations.	Civil: not to exceed fine of $10,000 per day of violation. Criminal: $100 to $25,000 per day of violation. Civil action for damages may be initiated by Board if fish are killed as result of pollutant discharge.	Legislation is broad enough to cover nonpoint pollution. Statute specifically lists decayed wood, sawdust, shavings and bark as potential pollutants.	Sec. 62.1-194 of the Virginia Code prohibits depositing timber or like material into any waters of the state. Sec. 62.1-194.2 of the Code prohibits placing treetops or logs which obstruct the movement of fish or boats for more than one week in rivers or streams. Scenic Rivers Act (Sec. 10-167 to 10-175). Permitted activities on rivers or river segments are designated on an individual basis. Forestry uses have not been restricted to date. Act specifies that the continuance of forestry activities on designated rivers is encouraged. Wetlands Act (Sec. 62.1-13.1 to 62.1-13.20) specifically permits the harvesting of forest products in wetlands.

Table C.2--Significant features of water quality legislation in the North

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Connecticut	Water Pollution Control Act. Conn. Gen. Stat. Ann. Title 22a Sec. 416 to 471. Enacted 1958; amended 17 times, 1967 to 1987.	Department of Environmental Protection.	Department granted authority to develop plans for the prevention and control of water pollution. Department adopts water quality standards and regulations in compliance with the Federal Water Pollution Control Act; and issues discharge permits. Department empowered to issue corrective orders.	Civil: up to $10,000 fine per day of violation. Criminal: up to $25,000 fine and/or one year in prison per day of violation. False statement or misrepresentation: up to $10,000 fine and/or six months in prison.	The statute's definition of water pollution includes alterations of water resulting in changes in turbidity or temperature which may be harmful to fish or other aquatic life. Statute requires a permit for any discharge; regardless of whether or not the discharge may cause pollution.	River Protection Statute (Conn. Gen. Stat. Ann. T.25 Sec. 102pp to 102vv). Municipalities granted authority to establish river protection corridors and may restrict land use. Some towns along Connecticut River require forest management and sediment control plans for forest operations. Inland Wetlands Statute (T.22a Sec. 361 to 363). Permit required for filling or reclamation of wetlands, road construction and clear-cutting of timber. Stream Obstruction Statute (T.22a Sec. 361 to 363). Permit required for placement of fill or obstruction in coastal, tidal or navigable waters. Soil Erosion and Sedimentation Control Act (T.22a Sec. 326 to 329). Municipalities may adopt regulations to control erosion and sedimentation. Coastal Management Act (T.22a Sec. 90 to 112). Municipalities may issue zoning regulations for land use in coastal areas.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Delaware	Environmental Protection Act. Del. Code Ann. T.7 Sec. 6001 to 6060. Enacted 1953; amended 1982, 1983, 1984, 1985, 1986.	Department of Natural Resources and Environmental Control.	Department empowered to develop, administer and enforce pollution control programs. Department adopts rules and regulations and develops statewide water pollution management plan. Department issues permits for discharges and may grant variances to rules and regulations. Department also granted authority to publish a list of activities exempt from permitting procedure. Prior to issuance of permits, proposed activities must be approved by the county or municipality of jurisdiction through zoning procedures. Department may issue cease-and-desist orders for violations.	Civil: from $1,000 to $10,000 fine per day of violation. Criminal: from $50 to $500 fine per day for general violation of rule or regulation or permit condition. From $2,500 to $25,000 fine per day for willful or negligent violation. From $500 to $5,000 fine and/or six months imprisonment for false statement or misrepresentation. Department may initiate civil action to recoup cost of damages.	Authority granted Department is sufficiently broad to apply to nonpoint sources. Department list of activities exempt from regulation has not been published, to date. Rock, sand, decayed wood, sawdust, shavings, bark and agricultural wastes are listed as potential pollutants.	Sedimentation and Erosion Control Act (Del. Code Ann. T.7 Sec. 4001 to 4017) requires submission of sedimentation and erosion control plans for land disturbing activities. Most forestry operations are exempt from regulation. Pollution of Streams (T.7 Sec. 1112) prohibits the discharge of any wastes or deleterious substance in sufficient quantities to injure or destroy fish.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Illinois	Ill. Rev. Stat. Ch. 111 1/2 Sec. 1001 to 1052. Enacted 1970; amended 1972 to 1986, 14 times.	Environmental Protection Agency and Pollution Control Board.	Board adopts rules and regulations and establishes water quality standards. Agency recommends regulations for adoption by Board and administers certification and permit systems. Agency responsible for administering National Pollutant Discharge Elimination System program. Agency may take summary enforcement action and issue stop orders for violations.	Civil: up to $10,000 fine per violation and $1,000 per day of violation. Criminal: violations other than hazardous waste disposal: up to $25,000 fine per day of violation, in addition to any other penalties prescribed.	Prohibits placing of any contaminants on land so as to create a water pollution hazard. Potential pollutants include wood residues, sand, silt, rock and agricultural wastes. Water quality standards developed to insure waters are free of floating debris and unnatural turbidity with potential to harm aquatic life.	Fish Protective Regulations (Ill. Rev. Stat. Ch. 111 1/2 Sec. 1001 to 1052) prohibit deposit of wastes in waters or placing of wastes where they may wash into waters, which are harmful to aquatic life. Specifically prohibits deposit of trash, trees, or parts of trees in or along banks of water. Pollution of Streams (Ch. 34 Sec. 3116) grants authority to counties to prevent pollution and issue stop orders for the discharge of pollutants. Local Land Resource Management Planning Act (Ch. 85 Sec. 5803 to 5809) authorizes local government to adopt ordinances to control land use. Purpose of act includes forest land and natural resource conservation. Forest Preserves (Ch. 96 1/2 Sec 6308). Silvicultural activities are permitted in preserves. Prohibits deposit of debris, trees or tree limbs or shrubbery in or along banks of waters within preserves (state or county owned lands). (Continued on next page)

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Illinois (cont.)						River Conservancy Districts (Ch. 42 Sec. 383 to 410.1) requires the Board of Trustees of river conservancy districts to control pollution through their police powers. Soil and Water Conservation District Law (T. 5 Sec. 106 to 138.2). Directors of districts may adopt land use ordinances for the control of erosion and sedimentation and prevention of water pollution with the approval of three-quarters of district landowners in a referendum. Flood Water Control (Ch. 19 Sec. 65 and 70) requires a permit for placement of woody plant material in or along banks of streams or for construction of stream crossings. Flood plains (Ch. 19 Sec. 65F). Requires a permit for any type of construction in designated floodplains.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Indiana	Stream Pollution Control Act. Ind. Stat. Ann. T.13 Sec. 1-3-1 to 1-3-18. Enacted 1943; amended 1945, 1949, 1957, 1978, 1985, 1987.	Stream Pollution Control Board and Department of Environmental Management.	Board adopts rules and regulations and establishes standards for the discharge of pollutants. Department issues permits for discharges. Board may issue cease-and-desist orders and bring enforcement actions for violations.	Civil action may be initiated for failure to comply with orders to cease polluting activities within 60 days of issuance. Additional civil penalty of $100 per day of violation past date specified in order or for additional days granted. Criminal: violations are Class B misdemeanor and subject to fine of up to $1,000 and/or 180 days imprisonment.	Act prohibits any discharges which may impair fish life. Broad definition of pollutant includes both organic and inorganic matter which is disposed of in any way into waters, including runoff and seepage.	Stream Obstruction Statutes (Ind. Stat. Ann. T.14 Sec. 2-5-9 and T.13 Sec. 2-4-4) prohibit the obstruction of any navigable waters or other waterway which prohibits the free passage of fish. Scenic and Recreational Rivers Preservation Act (T.13 Sec. 2-26-1 to 2-26-11) requires approval of the Department of Natural Resources Commission prior to harvesting below the high flood mark of designated rivers, which may be up to 200 feet. River Commission Act (T.13 Sec. 2-27-1 to 2-27-27). Activities which significantly alter the natural and scenic qualities of designated rivers are generally prohibited. Individual river commissions have authority to issue permits for activities otherwise prohibited. Exception to permitting authority: activities visible from five feet above water surface. Flood Control Act (T. 13 Sec. 2-22-1 to 2-22-20) prohibits obstruction of any floodway which could adversely affect fish, wildlife or botanical resources.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Iowa	Water Quality Act. Iowa Code Ann. Sec. 455B. 171 to 455B. 210. Enacted 1965; amended 13 times, 1969 to 1986.	Department of Natural Resources and the Water Pollution Control Commission.	Commissioner establishes water quality standards and rules for discharges in accordance with the Federal Water Pollution Control Act. Department enforces rules and standards and issues permits. Department authorized to issue cease-and-desist orders.	Civil: up to $5,000 per day of violation. Civil penalty provided in Act as alternative to criminal. Criminal:up to $10,000 per day of violation. Repeated offense: up to $20,000 per day of violation. False statement or misrepresentation: up to $10,000 and/or six months in prison.	Definition of water pollution includes any alteration or contamination which is injurious to fish or other aquatic life. Act authorizes local governments to adopt ordinances and regulations for land use in flood plain areas.	Erosion Control Law (Iowa Code Ann. Sec. 467A.2 to 467A.75). Erosion control plan not required for timber harvest. However, operations must not exceed soil loss limits established for each district. Logging road construction may require erosion control plan if more than 25,000 square feet of soil are disturbed. Sec. 109.14 prohibits the obstruction of waters which impede the free passage of fish. Scenic Rivers System Act (Sec. 108A.1 to 108A.7) authorizes political subdivisions to zone or otherwise establish land use controls along designated rivers.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Maine	Protection and Improvement of Waters Act. Maine Rev. Stat. Ann. T.38 Sec. 361 to 489. Enacted 1954; amended 12 times, 1957 to 1985.	Board of Environmental Protection and municipalities under authority of the Board.	Board charged with the control and prevention of water pollution. Board issues permits and licenses, establishes water quality standards and parameters for the classification of waters. Board also establishes criteria for mixing zones required for the dilution of pollutants.	Civil: from $100 to $10,000 fine per day of violation. Criminal: up to $25,000 per day of violation. False statement or misrepresentation: up to $10,000 and/or six months in prison. Court may order restoration of site.	Statute includes sand, dirt, rock and agricultural wastes of any kind as potential pollutants. Prohibited deposits include sawdust, chips, bark and other forest products refuse. Permit may be required for operations conducted below high water mark of ponds over ten acres and in protected river corridors. In wetlands, "normal and customary" forest practices are exempt from permit requirement. Log driving is prohibited and the storage of logs in waters requires a permit. Permit required for dredge and fill operations and for construction of permanent structures within or adjacent to streams or rivers when spoil, fill or structure may wash into waters. Under Shoreline Zoning, (Sec. 435 to 447) timber harvesting within 250 feet of normal high water mark of waters, but not associated road construction, is exempt from permit requirements. Timber harvesting is prohibited within shorelands of ponds (Continued next page)	Coastal Management Policies (Maine Rev. Stat. Ann. T.38 Sec. 1801 to 1803) establishes general policies for the protection of coastal resources, with potential application to forestry. Maine Land Use Regulation Law (T.12 Sec. 681 to 689) authorizes Land Use Regulation Commission to issue rules, regulations and standards for land use in unorganized townships. Harvesting and road construction may require permit and/or compliance with standards. Standards limit clearcut size and restrict slash disposal. Regulations require control measures be used to minimize sedimentation and erosion during road and stream crossing construction.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Maine (cont.)					larger than ten acres in resource protection districts. Creation of clearings within 50 feet of the high water mark of a shoreline is also restricted.	
Maryland	Water Pollution Control and Abatement. Ann. Code of Md. T.8 Sec. 1401 to 1502. Enacted 1957; amended 13 times, 1973 to 1987.	Department of the Environment.	Department is responsible for development and implementation of pollution control programs. Department adopts rules and regulations, establishes water quality standards, and issues permits. Department may order corrective actions for violations.	Civil: up to $10,000 fine per day. Criminal: violation considered misdemeanor. Fine of up to $25,000 per day and/or imprisonment for up to one year. Penalty doubled for repeated offenses. Falsification or misrepresentation: fine of up to $10,000 and/or six months in prison.	Statute prohibits the emission of soil or sediment into waters or placement of soil or sediment where it is likely to be washed into waters by runoff of precipitation or by any other flowing waters.	Scenic and Wild Rivers Act (Ann. Code of Md. T.8 Sec. 401 to 411). Harvesting in some river corridors is regulated by local ordinances. Sediment Control Act (T.8 Sec. 1101 to 1104). Sediment control plan for harvests disturbing 5,000 square feet or more of soil, or which cross watercourses with drainage area in excess of 400 acres (100 acres for trout streams). Watershed Sediment and Waste Control (T.8 Sec. 1201 to 1210). Permits required for excavating, grading or filling operations in Severn or Patuxent watersheds. Chesapeake Bay Critical Area (T.8 Sec. 1801 to 1816) applies to all land within 1,000 feet of mean high tide. Commercial harvests require approval of forest mgmt. & sediment control plans by district forestry board. Harvesting prohibited within 50 feet of tidal waters and perennial streams. Clearcutting other than loblolly pine or tulip poplar prohibited within 100 feet of these waters; road construction regulated too.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Massa-chusetts	Clean Waters Act. Mass. Gen. Laws Ann. Chap. 21, Sec. 26 to 53. Enacted 1966; amended 14 times, 1967 to 1985.	Division of Water Pollution Control within the Department Environmental Quality Engi-neering.	Division has broad authority to promulgate rules and regulations, establish minimum water quality stan-dards, and issue permits. Division may also issue cease-and-desist orders against violators.	Civil: up to $10,000 fine per day of violation. Criminal: fine of $2,500 to $25,000 and/or one year in jail. Depart-ment may order correc-tive action for violations.	Statute's definition of "pollutant" includes any element of agricul-tural, industrial or commercial waste, including runoff, whether originating at a point or major non-point source. Regula-tions exempt silvicul-tural operations including road con-struction from which there is natural runoff. Act specifies, however, that some silvicultural opera-tions, such as stream crossings for roads, may require a Section 404 permit.	Scenic and Recreational Rivers and Streams (Mass. Gen. Laws Ann. Chap. 21 Sec. 17B). Counties may regulate, restrict or prohibit activities which could alter or pollute protected rivers and streams. Ordinances could be adopted to restrict silvicultural activities. Protection of Coastal Wetlands (Chap. 130 Sec. 105). Activities which involve dredge or fill or otherwise alter, or pollute lands subject to tidal action may be regu-lated, restricted or prohibited. Alteration of Lands Bordering Waters (Chap. 131 Sec. 40) requires written notice of intent to fill, dredge, or alter freshwater or coastal wetlands or any land subject to tidal action and a plan describing ac-tivities and their effect on the environment. Pollution of Coastal Waters (Chap. 130 Sec. 23 to 27) prohibits discharge of injurious substances, including sawdust and shavings, which directly or indirectly injure fish in coastal waters. Forest Cutting Practices Act (Chap. 132 Sec. 40-46) requires Intent to Cut/Cut-ting Plan for harvesting. (Continued on next page)

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Mass. (cont.)						Also requires additional wetlands or steep slopes plan, if applicable. Wetlands plan exempts operations from state Wetlands Law (Chap. 131 Sec. 40). Regulations address harvesting systems, skid trail location, stream crossing and road construction. Also limit clearcut size and require buffer and filter strips along streams. Additional rules for wetlands and steep slopes.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Michigan	Act establishing Michigan Water Resource Commission. Michigan Compiled Laws, Title 3, Sec. 520 to 532. Enacted 1929; amended 1941, 1947, 1949, 1963, 1965, 1968, 1972, 1977.	Michigan Water Resources Commission.	Commission authorized to regulate the storage or discharge of any substance which may affect water quality. Commission establishes water quality standards and issues permits for discharges. Commission has control over alterations of watercourses, floodplains, rivers and streams and may prohibit their obstruction. Act prohibits filling or grading lands located in flood plains or streambeds, except for agricultural purposes, without a permit. Copper or iron mining operations may be exempted from this provision.	Civil: up to $10,000 fine per day of violation. Criminal: from $2,500 to $25,000 fine per day of violation. Penalty doubled for repeated offense. Violator liable for restitution of damages to natural resources. Courts may impose probation in addition to fines.	Act prohibits discharge of any substance which is injurious to the value or utility of riparian lands or to fish, aquatic life or plants.	Stream Obstruction Statutes (Mich. Compiled Laws T.9 Sec. 334, T.13 Sec. 1657, T.9 Sec. 1175, T.18 Sec. 231) prohibit obstruction of streams or navigable waters with logs, lumber, apparatus or waste materials which prevent the free passage of fish or obstruct navigation. Soil Erosion and Sedimentation Control Act of 1972 (T.13 Sec. 1820(1) to 1820(17)). Counties delegated authority to enforce rules and regulations issued by the Commission and issue or deny permits for activities which may result in erosion or sedimentation. Empowers local governments to adopt more stringent requirements than issued by Commission. Act exempts logging from regulation. However, stream crossings constructed to conduct operations may require a permit. Shorelands Protection and Management Act (T.13 Sec. 1831 to 1845) empowers Commission and local governments to adopt rules for land use along Great Lakes shorelands. Commission rules may restrict cutting or vegetation, requires buffer strips be retained and/or management plans in designated areas. (Continued on next page)

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Michigan (cont.)						Inland Lakes and Streams Act (T.11 Sec. 475 (1) to 475 (15) requires a permit for activities which: (1) dredge or fill bottomland; (2) place a structure in bottomland; or (3) structurally interfere with natural flow of inland lake or stream. Permit required for both temporary and permanent stream crossing. Natural Rivers Act of 1970 (T. 11 Sec. 501 to 516). Counties and townships may require a permit or restrict or prohibit cutting timber along some rivers. Act limits restricted corridor to 100 feet. Gaemaere-Anderson Wetlands Protection Act (T.18 Sec. 595 (51) to 595 (72)) exempts silviculture, lumbering, and harvesting of forest products from permit requirements. Act also exempts minor drainage to improve site for silviculture or lumbering.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Minnesota	Water Pollution Control Act. Minn. Stat. Ann. Sec. 115.01 to 115.83. Enacted 1961; amended 15 times, 1963 to 1987.	Minnesota Pollution Control Agency.	Agency granted broad powers to establish rules and standards and issue permits and orders for pollution control. Enforcement powers include actions to recover civil penalties, injunctions and actions to compel performance.	Criminal: violations considered misdemeanor. Fine from $300 to $40,000 per day and/or one year imprisonment. Second conviction: up to $50,000 per day and/or two years imprisonment. Civil: up to $10,000 fine per day of violation. Exempted from civil liability are acts of God, war, negligence of the state, or sabotage or vandalism.	Definition of "other wastes" includes sawdust, shavings, bark, sand and agricultural wastes. Pollutants include any discharges which are harmful to fish or other aquatic life.	Pollution of Waters Act (Minn. Stat. Ann. Sec. 144.35) and Work in Public Waters Act (Sec. 105.42) prohibit the deposit of any sewage or other material which will impair the health of water or placing materials where they may fall or drain into a pond or stream. Sec. 105.42 includes excavation or filling activities. Public Waters and Wetlands Act (Sec. 105.37 to 105.391) empowers state to regulate activities which will change the course, current or cross-section of wetlands or public waters. Prohibits draining wetlands unless replaced with wetlands of equal or greater value. Silviculture not exempted. Any physical change below high water mark would require a permit, including logging road and skid trail construction and associated bridges and culverts. Shoreland Development Act (Sec. 105.485) requires counties and municipalities to adopt an ordinance for use and development of shorelands consistent with state model ordinance and rules. (Continued on next page)

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Minnesota (cont.)						Current rules emphasize destruction of view. Proposed rules for silviculture include (1) maintaining buffer strips adjacent to waters; (2) restrictions for landing and yarding areas and skid and haul roads; (3) prohibition of clearing of vegetation on slopes 30 percent or greater; (4) requiring prompt reforestation; and (5) requiring permit and erosion control plan for forest conversions. Excessive Soil Loss Act (Sec. 40.19 to 40.27) encourages local governments to adopt soil loss ordinances consistent with state model and minimum standards. Forestry included as an "agricultural activity" in rules. A plan may be required for restoring erosion damage after harvest if soil loss is excessive. County Planning and Zoning Act (Sec. 394.21 to 394.26) grants authority to Board of County Commissioners to establish zoning districts for land use, including forestry. Floodplain Management (Sec. 104.01 to 104.07) encourages local governments to adopt ordinances for land use in floodplains. Ordinances restrict fill, deposit or other use which unduly (Continued on next page)

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Minnesota (cont.)						restrict the capacity of floodplains. Some counties require permit for logging road construction in floodplains. Wild and Scenic Rivers Act (Sec. 104.31 to 104.40). State rules prohibit clearcutting within designated distances of rivers depending on river classification. Trees greater than four inches in diameter may be removed provided continuous tree cover is maintained. County regulations may be adopted which are more restrictive than state.
Missouri	Clean Water Act. Ann. Missouri Stat. T.12 Sec. 644.006 to 644.141. Enacted 1972; amended 1973, 1982, 1983, 1987.	Missouri Clean Water Commission and Department of Natural Resources.	Commission granted broad powers to issue orders and permits. Commission adopt and enforce rules and regulations, and prescribes water quality standards. Department may initiate civil action to force compliance with standards and rules.	Criminal: $2,500 to $25,000 fine and/or one year imprisonment per day of violation. Subsequent convictions: up to $50,000 fine and/ or two years imprisonment. False statement or misrepresentation: up to $10,000 fine and/or six months imprisonment. Civil: up to $10,000 fine per day of violation. Action may be brought to restore damages.	Definition of pollution includes alterations of water turbidity and contamination which is harmful to fish and other aquatic life. Act states that contamination includes both direct and indirect sources including surface runoff. Commission authorized to conduct a planning process to identify silvicultural nonpoint sources of pollution and to develop procedures and methods, including land use requirements, to control sources.	Steam Obstruction Statute (Ann. Missouri Stat., T.16 Sec. 252.200) prohibits obstructing the free passage of fish through any waters of the state. Water Conservancy District Act (T.16, Sec. 257.010 to 257.490) empowers citizens to form river basin conservancy districts through which land use may be regulated.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
New Hampshire	Water Pollution and Disposal of Wastes Act. N.H.R.S. Ann. Sec. 149:1 to 149:26. Enacted 1947; amended 11 times, 1955 to 1986.	New Hampshire Water Supply and Pollution Control Commission.	Commission has broad authority for the discharge of pollutants in waters and alterations near waters. Commission issues permits, promulgates rules and regulations, and classifies waters into one of four quality types. Commission may issue cease-and-desist orders.	Civil: up to $10,000 fine per day of violation. Criminal: up to $25,000 fine per day and/or six months in prison.	Act includes decayed wood, sawdust, bark, shavings and other substances harmful to human, animal, fish or aquatic life as potential pollutants. Prohibits placing trees or parts thereof in waters. Detailed plans must be submitted for forest operations in lands bordering water. Upon approval of the Commission, a permit will be issued. Requirement can be circumvented by signing of an agreement to implement appropriate BMP's to protect water quality. If operator fails to comply with BMP's, he is subject to penalties under the law and will be required to submit detailed plans for future operations.	Fill and Dredge in Wetlands (N.H.R.S. Ann. Sec. 483-A:1 to 483-A:7) requires permit for some activities in wetlands such as construction of stream crossings. Slash and Mill Waste (Sec. 224:44-b) prohibits disposal of slash in waters or within 25 feet of streams or rivers capable of floating a canoe or within 50 feet of navigable rivers or ponds greater than 10 acres. Limits slash disposal to 4 feet above ground between 50 and 150 feet of ponds greater than 10 acres or navigable streams or rivers. Cutting of Timber near Public Waters and Highways (Sec. 224: 44-a) limits cutting of trees to 50 percent of basal area within 150 feet of ponds greater than ten acres and navigable streams and rivers or within 50 feet of any other continuously flowing stream or river.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
New Jersey	Water Pollution Control Act. N.J. Stat. Ann. T.58 Sec. 10A-1 to 10A-37. Enacted 1977; amended 1981, 1984, 1986.	Department of Environmental Protection.	Commissioner of Department of Environmental Protection empowered to adopt rules and regulations, classify bodies of water and establish water quality standards for each class, and issue permits. Commissioner may, by regulation, exempt certain discharges from permit requirements. Possible exemptions include: (1) Uncontrolled nonpoint source discharges composed entirely of stormwater runoff; (2) nonpoint discharges in general; and (3) discharges of dredge and fill material.	Civil: up to $50,000 fine per day of violation. Criminal: fine of $5,000 to $50,000 and/or six months imprisonment per day of violation. Penalty doubled for repeated offense. False statement or misrepresentation: up to $20,000 fine and/or up to six months imprisonment. Assessment of civil liability for damages.	Act defines pollutants to include dredged spoil, rock, sand, agricultural waste or other residue. Silvicultural nonpoint source pollution could be exempted at the discretion of the Commissioner through regulations.	Flood Hazard Area Control Act (N.J. Stat. Ann. T.58 Sec. 16A-50 to 16A-66) requires permits for land disturbing activities affecting more than 5,000 square feet in flood hazard areas. Logging road construction may require a permit for extensive operations. Stormwater Management Plan (T.40 Sec. 55D-93 to 99). Municipalities required to adopt ordinances to minimize stormwater runoff and control nonpoint source pollution. "Nonpoint pollutants" include silvicultural sources. To date, ordinances have not been adopted. Soil Erosion and Sediment Control Act (T.4 Sec. 24-39 to 24-55). Soil Conservation Committee establishes standards and may require plans for the control of sedimentation and erosion from land disturbing activities involving 5,000 square feet or more of soil. To date, plans have not been required for silvicultural operations. Could be applied when large areas are disturbed during logging road construction. Wild and Scenic Rivers Act (T.13 Sec. 8-45 to 8-54). Department of Environmental Protection establishes minimum standards for land use in river corridors. (Continued on next page)

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
New Jersey (cont.)						Municipalities may adopt rules and regulations more stringent than Department. To date, no regulations or standards have been adopted. Pinelands Protection Act (T.13 Sec. 18A-1 to 18A-49) applies to approximately one million acres. Pinelands Commission requires harvesting plan be approved by the Bureau of Forestry prior to issuance of a permit by the Commission. Act prohibiting the draining of deleterious substances into waters (T.23 Sec. 5-28 to 5-29.1) exempts application of chemicals on forest crops. Freshwater Wetlands Act(T.13 Sec. 9B-1 to 30) regulates dredging, draining, filling, and other alterations of freshwater wetlands, including cutting of trees. Exempt from permitting process are "normal" silvicultural operations; includes harvesting and road construction in compliance with BMP's and a management plan approved by State Forester. Conversion of wetlands to manipulate tree species composition not exempt.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
New York	Water Pollution Control Act. Cons. Laws of N.Y. Art. 17 Sec. 0101 to 1907. Enacted 1972; amended 12 times, 1973 to 1987.	Department of Environmental Conservation	Department determines classifications of waters and adopts standards of quality and purity for each class. Department adopts rules and regulations to prevent pollution and issues permits. Department authorized to issue cease-and-desist orders for violations.	Civil: up to $1,000 fine per violation Criminal: fine from $2,500 to $25,000 per day of violation and/or one year imprisonment. Penalty double for repeated offenses.	Potential pollutants include substances which may be harmful to aquatic life. Prohibited "industrial wastes" include substances resulting from the development or recovery of any natural resource, which may be a potential pollutant. Prohibited "other wastes" include sawdust, decayed wood, shavings and bark. Act prohibits the discharge of both organic and inorganic matter which is not in compliance with Department standards.	Wild, Scenic and Recreational Rivers (Cons. Laws of N.Y. Art. 15 Sec. 2701 to 2723). Regulations require a permit for clearcuts in excess of 25 acres and include numerous rules for road and stream crossing construction, felling and skidding trees, debris removal, and buffer strips in river corridors. Fish and Wildlife Law (Art. 11 Sec. 0501 to 0536) Act prohibits the deposit of sawdust, shavings, or bark in waters in amounts which would harm fish or wildlife. Prohibits obstruction of waters which hinder the passage of fish. Prohibits the deposit of soil in streams or on banks of streams inhabited by trout. Freshwater Wetlands Regulations (Art. 24 Sec. 0701 to 0705). Act regulates draining, dredging or filling of freshwater wetlands. Permits required for clearcuts within wetlands, but are usually not granted. Selective cutting is exempt from regulation. Clearcuts in areas adjacent to wetlands require permit, and are usually granted. Stream Protection Law (Art. 15 Sec. 0501 to 0503). Act requires a permit for changing, modifying, or disturbing streams or (Continued on next page)

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
New York (cont.)						banks of streams within designated water classifications. Excavation or fill in navigable waters (Art. 15 Sec. 0505) requires permit for excavation or fill below the high water mark of navigable waters and in adjacent wetlands or marshes.
Ohio	Water Pollution Control Act. Ohio Rev. Code Ann. Sec. 6111.01 to 6111.99) Enacted 1953, amended 14 times, 1955 to 1984.	Department of Environmental Management	Department promulgates rules and regulations and establishes water quality standards. Department issues permits and orders for pollution control. Act prohibits placing any waste in a location where water pollution could result without a permit. Exception: application or runoff of materials used for agricultural purposes. Department may seek injunction against violators.	Criminal: up to $25,000 fine and/or one year imprisonment.	Definition of pollutant includes decayed wood, sawdust, bark shavings, other wood debris and silt.	Pollution Control Program (Ohio Rev. Code Ann. Sec. 1501.20) requires Soil and Water Conservation Commission to develop program for agricultural pollution abatement to meet state water quality standards. Commission currently has no enforcement power. Department of Natural Resources is seeking amendment for $100 fine per day for pollution resulting from agricultural (including silvicultural) sedimentation. Watershed District Law (Sec. 6105.01 to 6105.99) prohibits obstruction of restricted floodway without consent of Board of Directors of watershed districts.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Pennsylvania	Clean Streams Act. Penna. Stat. Ann. T.35 Sec. 691.1 to 691.1001. Enacted 1937; amended 1945, 1956, 1965, 1970, 1976, 1978, 1980.	Department of Environmental Resources and Environmental Quality Board	Department has broad authority to adopt rules and regulations and establish standards to control pollution. Department issues permits for discharges and may seek injunctions and issue orders for abatement of polluting activities.	Civil: up to $10,000 fine per day of violation. Criminal: from $100 to $10,000 fine for violation. Default of payment: 90 days imprisonment. Willful or negligent violations: from $2,500 to $25,000 fine and/or one year imprisonment. Additional offense within two years of first offense: from $2,500 to $50,000 fine and/or two year imprisonment.	Act defines pollution to include contamination which is injurious to fish or other aquatic life and alterations resulting in changes in water temperature. Exempt from penalties is pollution in the form of sediment resulting from an act of God on land for which an approved conservation plan has been implemented. By inference, other causes of sedimentation, including that resulting from forest operations, would be subject to regulation. Under regulations issued under the Act, detailed, site specific plans are required for erosion and sedimentation control for silvicultural operations where earth disturbing activities exceed 25 acres.	Flood Plain Management Act (Penna. Stat. Ann. T.32 Sec. 679.101 to 679.601). Plans to control obstruction of flood waters implemented by local governments. Some may regulate forest operations. Storm Water Management Act (T.32 Sec. 680.1 to 680.17). Local governments may enact ordinances for the control of runoff and sedimentation and erosion. Some may regulate forest operations. Dam Safety and Encroachment Act (T.32 Sec. 693.1 to 693.27). Permit required for both permanent and temporary water crossings constructed during harvesting operations. Scenic Rivers Act (T.32 Sec. 820.21 to 820.29). Recommended guidelines for silvicultural operations have been issued. Protection of Property and Water Act (T.30 Sec. 2501 to 2506). Permits required for activities which alter streams, water or watersheds in any way which may damage fish.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Rhode Island	Water Pollution Control Act. Gen. Laws of R.I. T.46 Sec. 12-1 to 12-37. Enacted 1920; amended 24 times, 1921 to 1986.	Department of Environmental Management	Department empowered to adopt standards and issue rules and regulations for the control of water pollution. Department classifies waters and issues permits for the discharge of pollutants. Department has authority to issue stop orders for violations.	Civil: up to $5,000 fine per day of violation. Criminal: up to $10,000 fine and/or 30 days imprisonment per day of violation. False statement or misrepresentation: up to $5,000 and/or 30 days imprisonment.	Act defines pollutant to include agricultural wastes. Legislation is sufficiently broad to cover nonpoint sources of pollution. Act prohibits placing any pollutant where it is likely to enter waters or to place any solid waste materials, junk or debris whether organic or inorganic in waters.	Soil Erosion and Sediment Control Act (Gen. Laws of R.I. T.45 Sec. 46-1 to Sec. 46-6). Cities and towns may require permits for earth disturbing activities. Act exempts harvest activities on property utilized for silvicultural purposes. Road construction may require a permit and erosion control plan if extensive or if involving slopes greater than ten percent. Freshwater Wetland Act (T.2 Sec. 1-18 to 1-27) prohibits excavation, draining or filling of wetlands. Also prohibits placing garbage, earth, rock, sand or other materials in waters. Harvesting operations may require a management plan, depending on extent of operations.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Vermont	Water Pollution Control Act. V.S.A. T.10 Sec. 1250 to 1384. Enacted 1947; amended 15 times, 1949 to 1987.	Vermont Resources Board and Department of Water Resources and Environmental Engineering within the Agency of Environmental Conservation.	Act establishes classification parameters for waters. Board adopts standards of water quality for various classes. Agency establishes rules and regulations for pollution control and has authority to issue permits. Act addresses stormwater runoff and alteration of wetlands. Agency authorized to bring suit to force compliance with Act and may order corrective action for violations.	Civil: up to $10,000 fine per day of violation. Criminal: up to $25,000 fine and/or six months imprisonment per day of violation. Falsification or misrepresentation: up to $10,000 fine and/or six months imprisonment. Sawmill Waste: $100.00 fine per offense.	Act prohibits deposit of sawdust, shavings, edgings, slabs or other sawmill refuse into waters or placing wastes in such a manner as to wash into waters. Forest operations must comply with acceptable management practices (AMP's) to be exempt from permitting requirements under Act. Department of Forests, Parks and Recreation issues AMP's.	Protection of Navigable Waters and Shorelands Act (V.S.A. Sec. 1421 to 1426). Municipalities authorized to adopt shoreland zoning bylaws to control pollution and protect fish and aquatic life. Some forest operations may be restricted. Water Resources Management Act (Sec. 901 to 923) grants broad authority to Water Resources Board for protection of wetlands. Board may not adopt rules which restrain silvicultural activities without consent of the Department of Forests, Parks and Recreation. An Act Relating to Regulation of Wetlands (Senate Bill 95 No. 188). Sections related to forestry duplicate Water Resource Management Act. Rules and regulations currently being developed will restrict some forest operations such as draining wetlands to harvest and road and stream crossing construction in wetlands.

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
West Virginia	Water Pollution Control Act. W. Va. Code, Chap. 20, Art. 5A-1 to 5A-21. Enacted 1969; amended 1976, 1978, 1983.	Division of Water Resources (within Department of Natural Resources) under authority of Water Resources Board.	Division of Water Resources is authorized to carry out requirements of Federal Water Pollution Control Act; has permit issuing authority and may issue stop orders. Exception: law does not apply to farm ponds, industrial settling ponds and water treatment facilities.	Civil: fine not to exceed $10,000 per day of violation. Fine can be imposed only by civil action initiated in circuit court of county where violation occurs. Criminal: violation considered misdemeanor; punishable by fine of $100 to $25,000 per day of violation and/or up to one year in jail. Department of Natural Resources can initiate court action to recover costs of damage.	Law is sufficiently broad to include nonpoint pollutants under its provisions. Decayed wood, sawdust, shavings, and other wood residues are specifically listed as potential pollutants. Stringent water turbidity standards have been established. Exceptions for logging have been made where a site specific BMP plan is in effect.	Stream Obstruction Law (W. Va. Code, Chap. 61, Art. 3-47) prohibits any felling of timber that would obstruct a navigable or floatable stream. Natural Stream Preservation Act (Chap. 20, Art. 5B-1 to 17) prohibits activities which obstruct the free-flowing characteristics of designated streams without a permit. Act has not been applied to forest operations to date.
Wisconsin	Water and Sewage Act. Wis. Stat. Ann. Sec. 144.01 to 144.27. Enacted 1913; amended 15 times, 1919 to 1986.	Department of Natural Resources.	Department has broad authority for supervision and control over state waters. Department develops regional plans, establishes water quality standards, adopts rules and regulations, and issues permits for discharges. Department may issue temporary emergency orders to protect public health and stop orders for abatement of pollution. Department required to prepare comprehensive plan for application of municipal ordinances regulating navigable waters and shorelands. Act authorizes municipal construction site erosion control and storm water management zoning ordinances. Department required to develop standards for ordinances.	$200 to $5,000 fine per day of violation.	Prohibits the disposal of garbage or refuse where it is likely to be washed into water. Prohibited are discharges which are deleterious to fish and unnecessary siltation resulting from gross neglect of land erosion. Act establishes a nonpoint source pollution program providing technical and financial assistance. Department promulgates rules and standards concerning BMP's which must be met for cost sharing grants.	Wetlands Zoning Act (Wis. Stat. Ann. Sec. 61.351) requires villages to enact ordinances consistent with Department of Natural resources (DNR) minimum standards to protect shorelands. Access roads and stream crossings for logging operations may require permit and/or be subject to DNR standards. Shoreland Zoning on Navigable Waters Act (Sec. 59.971) requires counties to enact zoning ordinances to protect shorelands within 1,000 feet of lakes and ponds and 300 feet from rivers and streams. Clearcuts are limited to 30 feet for each 100 feet along shorelands within a 35 foot corridor. Slash Disposal Act (Sec. 26.12) (Continued on next page)

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Wisconsin (cont.)						requires timber owners or operators to remove logging slash from lakes and streams. Environmental Impact Statement (EIS) Act (Sec. 23.40). DNR determines whether EIS required based on information submitted when applying for permit. Permit required for stream crossing, therefore would be subject to review. Soil and Water Conservation Law (Sec. 92.02 to 92.16) requires Department of Agriculture to develop model ordinances for land use for adoption by counties and municipalities. Local ordinances may restrict land management practices which cause excessive erosion, sedimentation, non-point source pollution, or stormwater runoff. Ordinances must be approved in referendum. Wild Rivers Act (Sec. 30.26) designates Pike, Pine and Popple rivers for preservation. Requires DNR to work with counties and towns to establish program for river protection. Requires DNR to cooperate with USFS, timber companies, and private landowners in implementing land use practices. Some ordinances restrictive to forest practices have been adopted. Lower St. Croix River Preservation Act (Sec. 30.27) requires local (Continued on next page)

Table C.2--Significant features of water quality legislation in the North (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Wisconsin (cont.)						governments within designated protected areas to enact zoning ordinances in compliance with DNR guidelines and standards. Some ordinances have been restrictive to forest operations. Obstruction of Navigable Waters (Sec. 30.15) prohibits placing any obstruction in navigable water or tributaries which impedes navigation. Enlargement and Protection of Waterways Act (Sec. 30.19). Prohibits grading or otherwise removing top soil from banks of navigable waters which expose more than 10,000 square feet. Exempts agricultural land use. Changing of Streamcourse Act (Sec. 30.195) prohibits changing of course or straightening of navigable streams without permit. Under authority of Sec. 30.15, 30.19, and 30.195, both temporary and permanent stream crossings associated with logging require a permit.

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Arizona	Ariz. Rev. Stat. Ann. Sec. 49-201 to 321 resulting from additions, transfers and renumbering from Title 36 (enacted in 1956 with subsequent amendments). Enacted in 1986, effective 1987.	Department of Environmental Quality.	Department to promulgate water quality standards for all navigable waters, and develop a program for control of nonpoint source pollution into such waters. As part of this program, Department may establish BMP's for silvicultural activities. Forestry operations may require either individual or general permit at Department's option. Department may issue order requiring initiate compliance with statutory provisions; order will become final and enforceable within 30 days unless administrative hearing is requested. Department may request a temporary restr-aining order, preliminary or permanent injunction, or any other relief necessary to protect public health.	Civil penalties up to $25,000 per day per violation plus costs of litigation. Monetary damages to be paid to water quality assurance revolving fund. Criminal penalties range from felony to misdemeanor depending upon whether the violator was fully knowledgeable, neglige-nt, or reckless. Violators may also be responsible for remedial action costs.	Sections R9-21-202 to 205 of Administrative Rules and Regulations of Arizona 1986 prohibit water quality degradation. Otherwise, Department has no non-point source program beyond water quality standards. No forestry BMP's have been developed and none are expected. Only stan-dards likely to affect forestry practices are turbidity and tempera-ture. Regulations governing use of agricultural pesticides currently under development for protection of ground-water.	Ariz. Rev. Stat. Ann. Sec. 17-231, 237; requires cooperation between Department of Environmental Quality and Game and Fish Commission in abatement of water pollution injurious to wildlife. Commission may also bring suit in such matters. Ariz. Rev. Stat. Ann. Sec. 45-573 requires cooperation between Department of Environmental Quality and Department of Health Services on develop-ment of water quality management plans.

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Colorado	Colorado Water Quality Control Act. Colo. Rev. Stat. Sec. 25-8-101 to 703. Enacted 1973, supplemented 1986.	Department of Health through Water Quality Control Commission.	Policy objectives of legislation are two-fold: (1) protect quality of water resources, and (2) maximize the beneficial use of water resources consistent with the welfare of the state. Act does not supersede or materially diminish prior established water rights. Water Quality Commission within Department has authority to classify waters and promulgate water quality standards to control pollution. In developing standards, Commission is directed to consider whether pollution is from a natural source. Commission may promulgate regulations for the keeping of logs in water. Commission may not adopt standards for agricultural nonpoint sources of discharge which materially injure existing water rights. Department is to administer standards and programs developed by Commission. Department required to establish permit system for regulation of point sources of pollution; there are no particular provisions governing nonpoint sources. Department may issue "cease and desist" and "clean-up" orders. Failure to comply with such orders may result in temporary restraining order or injunction.	Civil: up to $10,000 per day of violation. Civil penalty credited to water quality control fund. Criminal: up to $12,500 if violator is negligent or reckless; up to $25,000 if violator is fully knowledgeable of the offense.	Standards that may be promulgated under the Act's authority which could impact forest management include those for turbidity, temperature, and suspended solids. At present, however, there are no standards for turbidity and suspended solids, and there is no program for regulation of nonpoint pollution sources. No forestry BMP's have been developed. An assessment and management plan for nonpoint sources of pollution is currently under development. No reference exists for excluding forest management operations from the point source pollution permit requirement as there is for irrigation return flow.	Colorado Soil Conservation Act (35-70-101 to 121) established State Soil Conservation Board to conserve and protect water resources, including: (1) the initiation of watershed planning to prevent flooding, and (2) the construction of structures to maintain soil stability and control erosion. Colo. Rev. Stat. 33-5-101 to 106 provides that no state agency may modify a watercourse without notification and a permit to insure protection of fishing streams. Law does not operate to diminish existing water rights and does not apply to irrigation projects. State Board of Agriculture has authority under Colo. Rev. Stat. 23-30-202 to "foster and promote" control of soil erosion on forest lands. Pesticide Applicators' Act (Colo. Rev. Stat. 35-10-101 to 125) provides that regulation of distribution, use, and application of pesticides is to involve balance of social utility and cost. Colo. Rev. Stat. 36-8-101 to 110. Regulates use of streams for floating logs to be used for any purpose; such use requires a permit from state engineer. Colo. Rev. Stat. 20-30-202 authorizes State Board of Forestry to (Continued on next page)

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Colorado (cont.)						"foster and promote" the control of soil erosion on forest lands. Colo. Rev. Stat. 23-30-301 states that policy objective of Colorado State Forest Service is to: "conserve forest cover on watersheds".

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Idaho	Environmental Protection and Health Act of 1972. Idaho Code, Sec. 39-101 to 118. Enacted 1947; amended 1973, 1979, 1980, supplemented 1987.	Department of Health and Welfare, Environmental Protection Division.	Department to promulgate and enforce regulations to enhance and preserve water quality. Department authorized to recommend rules to Board of Health and Welfare regarding water pollution, and issue permits as prescribed by law. Department also authorized to conduct investigations of violations of water quality standards. Department may us compliance schedule to assure timely compliance with regulations. Department authorized to implement water quality standards adopted by legislature.	Civil penalty of $1,000 per day of violation or $10,000, whichever is greater, plus reimbursement of remedial costs incurred by the state. Criminal: willful or negligent violation is misdemeanor offense punishable by fine of up to $300 for each violation. Each day a violation occurs is separate offense.	Water quality standards acknowledge economic necessity of nonpoint pollution activities. Management of nonpoint, pollution designed to only reduce such pollution; state's position is that it cannot be eliminated without severe economic impact. Generally, standards prohibit sediment in quantities which impair beneficial use of water. Nonpoint sources of pollution specifically include silt, sand and rock resulting from silvicultural activities, or from log storage in water. Silvicultural BMP's designed to protect water quality established in rules promulgated under Forest Practices Act (Idaho Code Sec. 38-1301 to 1312) These rules certified as approved water quality BMP's by Section 16.01-.2300.05 of water quality standards issued by Department. BMP's are mandatory for all forestry operations. Department responsible for evaluation and modification of BMP's to insure protection of beneficial (Continued on next page)	The Idaho Forest Practices Act (Idaho Code Sec. 38-1301 to 1312) authorizes promulgation of rules to establish BMP's to protect water quality during all phases of forest management. Drainage systems must control runoff waters from exposed surfaces. Slash and waste materials must not enter streams. Streams to be protected by avoiding skidding and cable yarding in or through them, and by retaining vegetation to shade water and stabilize soil. Chemical, road construction, and reforestation BMP's are also designed to protect water quality. BMP's last evaluated for effectiveness in protecting water quality in 1985. Results indicated that revision of Forest Practices Act rules was necessary. Rules revised in 1986 and incorporated into 1987 draft of Forest Practices Water Quality Plan. Feedback cycle for continuous proposal, implementation, and evaluation of BMPs also included. Violation of BMPs is misdemeanor. Stream Channel Protection Act (Idaho Code 42-3801 to 3812) protects against deleterious alteration of stream channels. Alterations impacting wildlife, aquatic life, recreation, (Continued on next page)

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Idaho (cont.)					use of water. Failure to meet water quality standards is <u>not</u> violation of law, but rather occasion for evaluating effectiveness of BMP's in protecting water quality. Operators failing to follow BMP's are subject to compliance schedule and fine. Injunctive and judicial relief are also available. Where BMP's have not been developed, activity must be conducted to minimize detrimental impact to water.	or other facets of water quality require a permit from Department of Water Resources. Act does not diminish existing water rights. Failure to obtain permit (misdemeanor) may result in fine of $150 to $500, plus additional fine of up to $150 per day that violation continues. Department has issued regulations governing stream channel alterations; these are certified as approved BMP's which are mandatory for forestry operations. Idaho Code Section 52-101 provides that unlawful obstruction of free passage or use, in customary manner, of any navigable lake, or river, stream, canal or basin is considered public nuisance. Idaho Code Sections 42-3601 to 3604 provide that Department of Lands is to cooperate with federal agencies in planning "works of improvement" (as per Watershed Protection and Flood Prevention Act of 1954, 16 USC Sec. 1001-1009) to prevent erosion, floodwater, and sediment damage. Idaho Code Sections 58-101, 140 to 147 provides that encroachments into lakes regulated by Board of Land Commissioners. Violators subject to fine ranging from $150 to $2500. (Continued on next page)

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Idaho (cont.)						Idaho Code Sections 58-401-405 provide that trees on state lands needed for conservation of irrigation water cannot be felled. Nonmerchantable dead and down timber on state land not required for water conservation (soil stabilization) may be informally sold by Department of Lands as firewood. Department of Water Resources must be given notice and opportunity to interpose objections prior to any timber sale.

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Kansas	Water Supply and Sewage Act. Kansas Stat. Ann. Ch. 65 Art. 16 Sec. 1 to 71W. Enacted 1097; amended 1909, 1923, 1927, 1967, 1974, 1977.	Department of Health and Environment.	Department establishes water quality standards and issues permits for the discharge of sewage. Department adopts rules and regulations for petroleum products storage, salt solution mining and laboratory certification where water sample analysis conducted. Department may issue stop orders for violations.	Criminal: $2,500 to $25,000 fine per day of violation. False statement: up to $10,000 fine per day. Civil: up to $10,000 per day of violation. Violators also liable for costs of restoration of damages.	Definition of pollutant includes alterations which are harmful to plant, animal or aquatic life.	Stream Obstruction Statutes (Kansas Stat. Ann. Ch. 32 Art. 1 Sec. 2, Ch. 82A Art. 3 Sec. 01 and Ch. 24 Art. 2 Sec. 06) prohibit: (1) obstructing the free passage of fish, (2) willful obstruction or filling of any drain, ditch or watercourse, and (3) obstructions which change or diminish the course, current or cross-section of waters. Floodplain Regulation Act (Ch. 12 Art. 2 Sec. 06) grants local governments the authority to establish floodplain zones and restrict land use through ordinances and regulations. Must be approved by Chief Engineer of Water Resources.

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Montana	Montana Water Quality Act. Mont. Code Ann. Sec. 75-5-101 to 75-5-641. Enacted 1967; amended 1971, 1973, 1974, 1975, 1977; supplemented 1985.	Department of Health and Environmental Sciences.	Purpose of Act is to protect both quality and quantity of water. Board of Health and Environmental Sciences authorized to adopt rules to achieve this objective, including classification of all waters and development of water quality standards. Standards and classes not to allow water to be degraded below its existing state, unless justified by economic or social development. Water quality standards need not exceed "natural" level of quality, where "natural" is defined as conditions or material present from water runoff over which man has no control or from developed land where all reasonable land, soil, and water conservation practices (BMP's) have been applied. New sources of pollution require permit; existing quality level must be maintained.	Civil: violators subject to fine of up to $10,000. Each day of violation constitutes separate offense. Criminal: willful or negligent violators subject to fine of up to $25,000 per day of violation and up to one year in prison. Subsequent convictions subject violators to $25,000 (maximum) fine and two years imprisonment.	Water quality standards focus on "natural" quality of water. Standards classify water by beneficial use; e.g. with respect to water classified for lower beneficial uses, greater deviation is allowed from level of pollutants naturally occurring in the stream. However, land management activities must not generate pollutants in excess of natural levels, regardless of stream class. Forestry BMP's developed by Department of State Lands include guidelines on road construction, harvesting, reforestation, and fire suppression. Under Memorandum of Understanding, both private and public forest managers have agreed to abide by established BMP's. Runoff and sedimentation acceptable if reasonable conservation practices (BMP's) are applied and beneficial uses of water are maintained. Exceptions to nondegradation rules allowed based on need for social and economic development.	Mont. Code. Sec. 76-13-101 to 601 provide for protection and conservation of forest, water, and range resources including regulation of streamflow and prevention of soil erosion. Mont. Code Sec. 75-6-101 to 13 provide for the protection of public water supplies. Prohibit building logging camps or roads near public water supplies, and industrial waste discharge from development of natural resources into such waters. The Natural Streambed and Land Preservation Act of 1975 (Mont. Code Sec. 75-7-101 to 124) prohibits unauthorized alteration of streambeds. Board of Natural Resources and Conservation authorized to issue regulations governing streambed alterations. Existing water rights are preserved. Failure to obtain permit may subject violator to fine of $25 to $500 per day plus remedial costs. Mont. Code Section 27-30-101 declares any obstruction or injury of navigable lake, river, bay, stream, or canal to be a nuisance. Mont. Code Sec. 75-7-201 to 217. Permit required for alteration of lakeshores.

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Nebraska	Environmental Protection Act. Rev. Stat. Neb. T.81 Sec. 1501 to 15,127. Enacted 1971; amended 12 times, 1972 to 1987.	Department of Environmental Control and Environmental Control Council.	Council adopts rules and regulations and sets standards for land, air and water quality. Department enforces provisions of the Act and Council rules and regulations. Department issues permits and may order violator to take corrective action. Department may grant variances. Act addresses litter control and disposal.	Criminal: up to $5,000 fine per day of violation and/or six months imprisonment. Civil: up to $5,000 per day of violation. Violators responsible for pollution resulting in the death of fish or wildlife are liable for compensation to state for restocking fish or replenishing wildlife. Prosecutions civil in nature except where clear criminal intent or knowing violation takes place.	Legislative authority sufficiently broad to include nonpoint sources of pollution. Purpose of Act includes the protection of fish and other aquatic life.	Floodplain Management Act (Rev. Stat. Neb. Sec. 31-1001 to 31-1031) requires a permit prior to obstruction of any watercourse or floodplain. Nebraska Natural Resource Commission develops and adopts minimum standards for incorporation into local governmental regulations. If not adopted by local governments, state regulations are automatically effective. Littering of Waters Act (Sec. 37-516) prohibits placing litter, trash, lumber or any material injurious to aquatic life in or near waters. Fishway Through Dams Act (Sec. 37-406) requires owner of dam or other obstructions across watercourse to insure flow of water sufficient for support of aquatic life. Stream Obstruction Statute (Sec. 455.160) prohibits and deems a nuisance any obstruction, diversion, filling up, ditching or draining any watercourse which has been prohibited by a resolution of the drainage district. Erosion and Sediment Control Law (Sec. 2-4601 to 2-4613) requires natural resource districts to adopt a program for implementation of state's erosion and sediment control plan, including soil loss (Continued on next page)

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Nebraska (cont.)						limits. Regulations must be at least as stringent as state's. Silvicultural activities are regulated under the law.
Nevada	Nevada Water Pollution Control Law. Nev. Rev. Stat. Sec. 445.131 to 445.354. Enacted 1973; amended 1977, 1979, 1981, 1985.	Division of Environmental Protection within Department of Conservation and Natural Resources.	Purpose of Act is to maintain quality of water consistent with beneficial uses and encourage use of pollution control methods. State Environmental Commission authorized to adopt water quality standards and regulations to control nonpoint source pollution. Standards must protect designated beneficial use of each stream segment. Standards proposed may vary from those based on recognized criteria if circumstances justify. If existing water quality exceeds applicable standard, water quality must be maintained at the higher existing level.	Director may issue corrective order to remedy diffuse source of pollution, but no civil or criminal penalty other than injunctive relief or temporary restraining order may be imposed. Diffuse source violators are excepted from monetary penalties.	Commission authorized to regulate diffuse (non-point) sources of pollution, including those emanating from silvicultural operations, in order to enforce non-degradation policy of water quality standards. Diffuse source discharges must be controlled by reasonable methods, based on particular location and economic capability of project or development. Silvicultural activities exempt from discharge permits unless certified as significant contributor to pollution. Municipalities charged with administering pollution control regulations promulgated by Commission. Forestry operations must utilize BMP's developed by State Board of Forestry under state Forest Practice Act, for non-point pollution control. Accepted forestry BMP's focus on five planning criteria for control of (Continued on next page)	Nev. Rev. Stat. Sec. 472.043 provides for the maintenance of vegetative cover on forest and watershed land in order to conserve water and soil. State Forester Firewarden is authorized to enter into contracts and take other measures designed to meet this objective. Nevada Forest Practices Act of 1955 (Nev. Rev. Stat. Sec. 528.010 to 528.120) requires issuance of a permit prior to any logging or cutting operation. Permit mandates submission of a logging plan, including proposed road construction specifications and erosion control measures. Tractor logging on slopes in excess of 30 percent gradient requires a variance from State Forester Firewarden. Erodibility of soil must be considered in variance application. Variance is also required to harvest trees, operate equipment or construct logging roads within 200 feet of a body of water. Erosion control is primary objective. Nevada Forest Practices Act of 1955 is also reflected (Continued on next page)

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Nevada (cont.)					runoff and sedimentation resulting from forest management activities: silvicultural treatments, logging methods, erosion control and road-building, hazard reduction, and forest protection.	in numerous management specifications to prevent runoff and sedimentation. State Forester Firewarden authorized to adopt BMP's under the Act. As discussed above, regulations under Water Pollution Control Law require that selected BMP's, depending on particular situation, be utilized in conjunction with forestry operations in order to control non-point water pollution. Nev. Rev. Stat. Sec. 503.430. Forest products processing waste such as sawdust, shavings, etc. introduced into water at any time in a manner deleterious to fish is a misdemeanor offense. Nev. Rev. Stat. Sec. 445.080 to 120 concern the protection of Lake Tahoe. Permit required for alteration of shoreline. Nev. Rev. Stat. Sec. 445.100 authorizes State Environmental Commission to adopt regulations concerning Lake Tahoe watershed. Any timber operations within Tahoe Basin must have approval of Tahoe Regional Planning Commission. Nev. Rev. Stat. Sec. 244.365. Boards of County Commissioners authorized to bring suit against any violator who deposits sawdust in any river or stream. Nev. Rev. Stat. Sec. 535.100. Lumber mills prohibited from obstructing natural stream flow.

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
New Mexico	Water Quality Act. N.M. Stat. Ann. Sec. 74-6-1 to 13. Enacted 1978; amended 1985, supplemented 1986.	Water Quality Control Commission (composed of officials from relevant state resource management agencies). Lead agency is Department of Health and Environment.	Commission authorized to adopt comprehensive water quality standards, regulations, and classifications. Fixed-term, individual variances can be granted if compliance with regulations is unduly burdensome. Commission may require permit, issued by constituent agencies charged with administration of standards and regulations. No regulation or water quality standard is adopted until after public hearing. Persons affected by regulations may petition court for relief. Court may strike regulations which are illegal, arbitrary, or not supported by evidence as to their purpose. Commission may seek injunctive relief. Commission <u>not</u> authorized to regulate pollution confined entirely within property on which it occurs.	Civil: penalties not to exceed $1,000 for each violation. Each day violation occurs is separate offense. Violators also liable for reasonable remedial costs. Violation of permit regulations is misdemeanor punishable by fine of $300 to $10,000 per day and one year imprisonment. Civil penalty for permit violation may not exceed $5,000 per day.	Water quality standards as such are unenforceable, but are primarily used as guidelines in evaluating discharge permits. The standards primarily affecting forest management activities are those protecting high quality cold water fisheries and domestic water supplies. These standards are very stringent. Water quality regulations prohibit disposal of refuse in a natural watercourse. Voluntary guidelines (BMP's) concerning most aspects of forest management have been certified by Water Quality Control Commission. State water quality management plan requires evaluation of effectiveness of voluntary BMP's in protecting water quality. Evaluation was due at end of 1987, after three year trial period.	Forest Conservation Act (N.M. Stat. Ann. Sec. 68-2-1 to 25) authorizes Forestry Division of Natural Resources Department to enforce all laws and regulations concerning logging and forest land conservation in order to maintain water quality. N.M. Stat. Ann. Sec. 30-8-2. Water pollution defined and declared a public nuisance, punishable as a misdemeanor. N.M. Stat. Ann. Sec. 17-4-29 requires persons floating logs, timber, or other forest products to deposit 1000 trout fingerlings annually into fisheries specified by Department of Game and Fish. Violation of statute is a misdemeanor, but statute is rarely if ever enforced. N.M. Stat. Ann. Sec. 72-10-2 authorizes commissioners elected from community to bring suit against any person who obstructs community spring, dam, or breakwater.

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
North Dakota	Water Pollution Control Law. N. Dak. Century Code, Sec. 61-28-01 to 61-28-06. Enacted 1967; amended 1969, 1971, 1973, 1975, 1983.	Department of Health and Water Pollution Control Board.	Department authorized to adopt rules and regulations for pollution control and establish water quality standards. Department issues permits and orders. Department may seek injunction to stop violations.	Criminal: up to $25,000 fine per day of violation and/or one year imprisonment. Penalty is doubled for second offense. Civil: up to $10,000 fine per day of violation.	Definition of pollution sufficiently broad to include nonpoint sources. Rock, sand and agricultural wastes are potential pollutants.	Soil Conservation District Law (N. Dak. Century Code, Sec 4-22-01 to 4-22-51). Land use regulations, including those for forestation and reforestation, may be adopted upon approval of two-thirds of the voters in the district through referendum. Obstruction of Watercourse Statute (Sec. 61-01-07) prohibits obstruction of or diversion of water from any ditch, drain or watercourse. Water Resource District Law (Sec. 61-16.1-09 to 61-16.1-52). District boards are authorized to adopt rules and regulations to prevent pollution or other misuse of water resources, streams or bodies of water. Permit required for draining ponds, sloughs, or lakes over 80 acres in size. State engineer empowered to take action to rehabilitate damages. Floodplain Management Act (Sec. 61-16.2-01 to 61-16.2-13) requires communities to adopt ordinances in compliance with national flood insurance program. Encourages communities to adopt and enforce floodplain management ordinances. Activities which increase base flood level prohibited. (Continued on next page)

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
North Dakota (cont.)						Little Missouri Scenic River Act (Sec. 61-29-01 to 61-29-06). Little Missouri River Commission empowered to promulgate management policies. Prohibits diversion of water for purposes other than agriculture, recreation, or dredging on Missouri River or tributaries of river.
South Dakota	Water Pollution Control Act. S. Dak. Code Laws Ch. 34A-2 Sec. 1 to 99. Enacted 1935; amended 15 times, 1939 to 1987.	Department of Water and Natural Resources under authority of Water Management Board.	Water Management Board authorized to issue water quality and effluent standards, classify waters as to beneficial uses, and establish rules for issuance of permits. Department issues permits and enforces permit conditions, and may issue orders for prevention, abatement, or control of pollution. Board may initiate court action against continuation of a violation or failure to comply with an emergency order.	Violations Class 1 misdemeanor. Criminal: up to $10,000 fine per day of violation and up to one years imprisonment. Civil: up to $10,000 per day of violation.	Definition of pollution includes alterations which exceed water quality standards for temperature or turbidity or which are likely to be harmful to birds, fish or other aquatic life. Potential pollutants include agricultural wastes, rock, sand and dredged spoil. Act infers it is applicable to non-point source discharges (Sec. 34A-2-39.1).	Restriction on Riparian Use Act (S. Dak. Code Laws Ch. 46 Sec. 5-1) prohibits polluting of natural springs or streams and activities which will alter their natural flow. Ch.46 Sec. 5-1.1 prohibits obstruction of navigable waters. Scenic Rivers Act (Ch. 46A-1-15 to 16) authorizes the Board of Water and Natural Resources to designate certain rivers or sections of rivers as wild, scenic, or recreational. After designation, no development shall occur which alters natural and scenic beauty. Act establishing Watershed Districts (Ch. 46A-14 Sec. 1 to 92). Watershed districts may be established to regulate the flow of streams, diversion of watercourses, and for imposition of preventative or remedial measures for control of soil erosion and siltation of watercourses. (Continued on next page)

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
South Dakota (cont.)						Soil Erosion and Sediment Damage Law (Ch.38-8A Sec. 1 to 28). Conservation district supervisors required to develop standards for control of erosion and sediment resulting from land disturbing activities. Political subdivisions responsible for granting permits. Process must insure activities are in compliance with standards. Some activities require submission of a plan. Agricultural activities, including forestry, are exempt provided standards are met. Protection of Fishing Waters Act (Sec. 41-13-1 to 41-13-11) prohibits the placement of sawdust, refuse or sedimentary materials into waters supporting game fish or to deposit it in such a way as to be carried into waters by natural causes.

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Utah	Utah Water Pollution Control Act. Utah Code Ann. Sec. 26-11-1 to 20. Enacted 1953; amended 1981, 1982, 1987, supplemented 1987.	Water Pollution Control Committee (composed of Director of Department of Health and eight members appointed by governor), under Department of Health.	Committee to develop programs to prevent, control, and abate new and existing water pollution. Committee may promulgate water quality and effluent standards, and classifications based on "reasonable uses". Discharge of any pollutant into water which menaces public health or impairs beneficial uses of waters is public nuisance. Governor may identify areas with water quality problems. Committee authorized to classify waters according to reasonable present and future use, and to issue water quality standards for each classification. Public hearing required prior to promulgation of water quality standards or classes. Committee may seek injunctive relief, or compliance order.	Civil: up to $10,000 per day, or up to $25,000 per day for willful or grossly negligent violation of Secs. 26-11-8(2) and 26-11-14. Subsequent violations: maximum penalty of $50,000 per day.	Forest lands generally full into "Class 1 and 2" lands for the protection of domestic, recreational and other beneficial water uses. Turbidity and temperature standards are the ones most relevant to forest management. Discharges which do not meet use classification standards are prohibited. Water quality standards require existing quality not be degraded, unless reduction justified by economic or social development. Water for human consumption protected by higher standards. Diffuse sources of pollution (non-point) into such waters must be controlled by either BMP's or regulatory programs. No statewide system of forestry BMP's exists, but certain local BMP's are certified under state 208 water quality plan. Voluntary inclusion of BMP's in timber sale contracts has been effective in meeting water quality standards. State-wide certification of forestry BMP's is underway.	Utah Code Ann. Sec. 23-15-6 prohibits pollution of water crucial to wildlife, including aquatic life. Utah Code Ann. Sec. 76-10-203 prohibits obstruction of irrigation watergates by floating logs or timber (antiquated). Utah Code Ann. Sec. 17-8-5.5 Counties may issue ordinances for protection of flood plains and channels. Utah Code Ann. Sec. 65-1-75 authorizes State Land Board to take necessary measures to prevent damaging floods and conserve state's natural resources. Statute recognizes role of improper timber management in flooding and authorizes Board to take steps to prevent flooding resulting from poor timber management. Utah Code Ann. Sec. 63-11-17.5 authorizes Division of Parks and Recreation to regulate development on lands within their jurisdiction. Division may impose regulations which are stricter than municipal ordinances.

Table C.3--Significant features of water quality legislation in the Rocky Mountain region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Wyoming	Wyoming Environmental Quality Act (Wyo. Stat. Sec. 35-11-101 to 1104. Enacted 1973; amended 1977, supplemented 1987.	Environmental Quality Department.	Discharge of any pollutant into water or alteration of physical, chemical, or biological properties of water is prohibited, except by permit. Division of Water Quality may develop regulations and water quality standards, including effluent limitations, and classify surface waters.	None specified.	Water quality standards serve as indicator as to whether BMP's should be developed. Violation of water quality standards by a nonpoint source is sufficient justification for development of BMP's. Water quality indicators relevant to forestry include water temperature and turbidity. To date, only turbidity has been used to limit forestry activities. Currently, no BMP's established for harvesting activities. Forest Management activities considered to have only minor impact on water quality in state. However, voluntary silvicultural BMP's are currently under development.	Wyo. Stat. Sec. 11-16-101 to 132 establish soil conservation districts to promote soil conserving practices. Wyo. Stat. Sec. 35-4-202. Sawmill owners who dump sawdust or chemical wastes into natural stream or lake thereby killing fish or rendering water impure are guilty of misdemeanor. Violation punishable by fine of $50 to $100 or imprisonment from one to six months. Each day of violation is separate offense. Wyo. Stat. Sec. 41-5-108 requires permit for floating logs in streams or rivers (antiquated). Wyo Stat. Sec. 41-8-101 to 126 create watershed improvement districts as subdistricts of soil conservation districts. Each improvement district must lie within a watershed. Improvement districts authorized to develop local watershed protection programs and ordinances, which could impact silvicultural activities.

Table C.4--Significant features of water quality legislation in the Pacific Coast region

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Alaska	Alaska Stat. Sec. 46.03.050 to 130, 320 to 800, 850. Enacted 1969, amended 1977, 1978, 1980, 1981, 1982, supplemented 1986.	Department of Environmental Conservation.	Law provides general prohibition of water, land and air pollution which has withstood constitutional challenge. Department may propose water quality standards and determine qualities and properties of water which indicate a polluted condition. After public hearings, Department authorized to develop water quality standards, classify waters as to minimum quality, or both. A short term variance from standards is available if economic or social development justify water quality reduction. Department also authorized to regulate use of pesticides. Activities impairing domestic water quality are prohibited as a nuisance. Department may issue compliance order for violation of water quality standards.	Civil penalty for initial violation ranges from $500 to $100,000 and up to $5,000 for each day violation continues. Penalty determined by degree of environmental damage, investigation and litigation costs, and economic savings realized by the violator. Violator is also liable for cost of restoring environment to original condition. Court may grant temporary or preliminary equitable relief. Violations punishable as misdemeanors. Each day a violation occurs is a separate offense.	Department has created water quality "use classes" which specify the degree of degradation not to be exceeded by human activity. Forest management is impacted by turbidity and sedimentation water quality parameters and pesticide regulation. Water quality standards consider social and economic factors as well as scientific criteria for protection of environment. Voluntary BMP's (in conjunction with Alaska Stat. 41.17.010) regulate forest management activities to meet requirements of water quality "use classes". Since BMP's are voluntary, standards may be enforced whether or not BMP's are being used.	Alaska Stat. Sec. 41.17.010 to 950 established Division of Forestry within Department of Natural Resources to execute forest management standards, policies, and guidelines. Department of Natural Resources may develop regulations for control of nonpoint sources of pollution, in cooperation with Department of Environmental Conservation. Scope of regulations includes all aspects of forest management with recognition of environmentally sensitive areas (e.g. stream buffer zone for eagle habitat) and BMP's. As voluntary guidelines, BMP's are not site-specific, but must be adapted to protect the water resources of the area. Department of Natural Resources is charged with review of proposed forest management plans and subsequent inspections to ensure compliance with water pollution regulations. Departments cooperate to evaluate plans to use broadcast chemicals. Violators are liable for civil fine up to $10,000, depending upon the amount of environmental damage, economic savings reaped by the violator, degree of intent or negligence, and past violations. (Continued on next page).

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Alaska (cont.)						Department of Natural Resources may issue a temporary stop order if violation is likely to result in irreversible harm. Department of Natural Resources may not usurp the statutory authority of other state agencies, unless authorized by Alaska Coastal Management Act or by the Department of Environmental Conservation. Alaska Stat. Sec. 16.05.870 to 900 provides that Department of Fish and Game shall identify specific water bodies important to spawning, rearing and migration of anadromous fish and review plans to use such waters (e.g. log dragging). Use of these waters without Departmental review and approval is a misdemeanor punishable by a $1,000 (maximum) fine. Violator is liable for restoration costs and other penalties imposed by the court. Alaska Stat. Sec. 16.10.010 prohibits the dumping of waste such as tree limbs or foliage, stumps, sawdust, planar shavings, earth or other debris into salmon spawning streams in support of the policies underlying Sec. 16.05.870. Permit for obstruction of such waters required by Department of Environmental (Continued on next page)

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Alaska (cont.)						Conservation. Violation of Sec. 16.10.010 is a misdemeanor punishable by a fine of $100 to $500. Alaska Stat. Sec. 16.20.1-85, 16.20.240 to 260 requires Department of Fish and Game to protect habitat of endangered species. Board of Fisheries and the Board of Game authorized to adopt regulations governing the taking of fish and game from critical habitat areas. Before land in these areas may be developed, leased or otherwise disposed of, the Department of Fish and Game must be notified. Written approval of the plans for disposal of the land from the Department may be required. 5 AAC 95.010 to 990, regulations for management activities on game refuges and critical habitat areas, require a permit for such activities and mitigation of adverse environmental impacts. 6 AAC 80.100 incorporates Alaska Stat. 41.17 into Alaska Coastal Management Program. Attorney General's opinion (J-66-224-79) indicates that the Department of Natural Resources's regulation of forest management practices preempts only the forest management standards of Alaska Stat. 46.40 (Coastal Zone Management Act), and not the entire act.

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
California	Porter-Cologne Water Quality Control Act, California Water Code. California Stat. Sec. 13000 to 13361. Enacted 1969; effective 1970. Amended 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1982, 1984, 1985, 1986.	Water Resources Control Board.	Authorizes Board to formulate water quality policy and to promulgate regulations for protecting water quality. Cities and counties may also adopt regulations, which must be consistent with those issued by Board. Identifies nine water quality regions and authorizes regional board for each. Provides for State Water Quality Control Plan, which is to include "basin" plans formulated by each regional board. Requires regional boards to establish water quality standards to protect beneficial uses. Authorizes regional boards to prescribe requirements for any discharge (essentially a permit program). If requirements have been prescribed, a waste discharge report must be filed with the Board.	Civil penalty for failure to file waste discharge reports and/or for deviations from discharge requirements ranges from $1,000 to $5,000 fine per day of violation, depending upon whether imposed administratively or judicially. Regional boards may issue cease and desist, and clean-up and abatement orders. Civil penalty for failure to adhere to cease and desist orders up to $6,000 per day of violation. If clean-up and abatement orders are ignored, state may take remedial action and the cost is imposed upon the violator.	Implications for forestry begin at the state level with the Water Resources Control Board. The Board has adopted a nondegradation policy which states that whenever existing water quality is better than that established by policy, such existing high quality will be maintained unless it can be demonstrated that any change will be consistent with maximum benefit to the people of the state, will not unreasonably affect present and anticipated beneficial use of such water, and will not result in water quality less than that prescribed by policy. Board has also required that each regional plan contain prohibitions against discharge of soil, silt, bark, slash, sawdust, or other organic or earthen material from logging operations into any stream or watercourse in quantities deleterious to fish, wildlife, or other beneficial uses, or against the placing of such materials at locations where they could pass into any (Continued next page)	Section 30417 of the 1976 California Coastal Act authorizes the Coastal Commission to identify special treatment areas within the coastal zone and to recommend forestry operation rules to the Board of Forestry which are adequate to protect the natural and scenic qualities of these areas. These rules impose higher than average standards for forestry activities within these areas. California Fish and Game Code (California Stat. Sec. 1603, 1606) provides that any person who obstructs or diverts any water body of those designated by the Department of Fish and Game must first notify the Department and follow procedures recommended by it; submitting a timber harvesting plan as required by the Forest Practice Act will constitute sufficient notice. California Statutes Section 5650 prohibits deposit of any slabs, sawdust, shaving, etc. into any waters of the state, with violation constituting a misdemeanor. CAlifornia Statutes Section 5093.68 essentially imposes the same requirements as do the forest practice rules on "special treatment areas" designated under the state Wild and Scenic River Act.

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
California (cont.)					stream or watercourse. The nondegradation policy and these two non-point pollution prohibitions summarize the Board's general position regarding protection of beneficial water uses from the adverse effects of timber harvesting and associated activities. Within this general framework, the nine regional boards carry the primary responsibility for on-the-ground regulation of water quality in accordance with their individual "basin" plans. With respect to forestry operations, these plans address the sources of pollution in each basin from timber operations, the types of impacts that such pollution may have on beneficial uses, and the water quality standards and objectives needed to protect water quality and beneficial uses. Regulation is effected through the water quality related rules promulgated under the state's forest practice act (Z'berg-Nejedly Forest Practice Act of 1973, Calif.Stat. Sec. 4511-4621). (Continued on next page)	

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
California (cont.)					These rules are minimum protection standards applicable to all commercial timber operations on non-federal timberlands. The current rules interact with the State Water Code by defining the beneficial uses of water to include those uses listed in the Water Code. With respect to non-point pollution, the rules cover silvicultural methods, harvesting practices and erosion control, watercourse and lake protection, and construction of logging roads and landings. The Forest Practice Act provides that timber operations will be exempt from the Water Code's waste discharge requirements if the forest practice rules promulgated under the Act are certified by the federal Environmental Protection Agency (EPA) as constituting best management practices (BMP's) for silviculture pursuant to Section 208 of the Federal Water Pollution Control Act. Such certification is presently pending. Until it is, (Continued next page)	

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
California (cont.)					effective, the regional boards can impose specific waste discharge requirements on timber operations. As a practical matter, however, they seldom do.	
Hawaii	Basic Water Pollution Statute. Hawaii Rev. Stat. Ch. 342-1 to 20, 31-35. Enacted 1972; amended 1973, 1980, 1982, 1984, 1985. State Water Code. Hawaii Rev. Stat. Ch. 175C-1 to 101. Enacted 1987.	Department of Health.	Water Pollution Statute: Department charged with prevention, control and abatement of water pollution. Department may establish water quality and effluent standards, and promulgate regulations to control pollution according to local conditions. Pollution discharge into state waters controlled by permit. Department may also approve variances, issue "cease and desist" orders, and initiate court action for injunctive relief. State Water Code: authorizes Commission on Water Resource Management to develop statewide water management areas and instream waterflow standards. Commission authorized to promulgate instream flow standards on stream-by-stream basis. Water management areas control water use in areas where resource is threatened. Instream flow standards describe waterflow necessary to protect variable interests in streams, including recreational, wildlife, and fishery interests. (Continued next page)	Civil: Department may initiate civil action to recover penalty. Criminal: for willful violation of any rule or regulation violator may be fined from $2,500 to $25,000 per day and may be imprisoned for up to on year.	Specifically designated pollutants include sediment, soil, and sand. Agricultural wastes also designated as potential pollutants. Established Water quality criteria relevant to forest management include those related to detrimental alteration of water turbidity or temperature.	Hawaii Pesticides Law (Hawaii Rev. Stat. Ch. 149A-31 to 33) Regulates the application of pesticides and provides for the suspension or cancellation of pesticide use if chemical residues are detected in drinking water, or under other conditions of "unreasonable adverse [environmental] effects". Hawaii Rev. Stat. Ch. 180C-2. County governments may enact ordinances for erosion and sediment control, primarily from urban sources. Hawaii Rev. Stat. Ch. 183-1 to 45. Department of Natural Resources responsible for protecting, extending, and increasing forest reserves for watershed management. Forest and water zones established in each county. Zones encourage highest economic use of resource consonant with water conservation. In subzones within reserve zones, Department may specify land use--including commercial timber growing. Regulations may prohibit unlimited (Continued on next page)

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Hawaii (cont.)			Commission must hold public hearing for discussion of proposed standards. Permit required to alter stream channels. Administrative rules implementing State Water Code currently under development.			cutting of forest growth or forestry practices detrimental to water conservation. Hawaii Rev. Stat. Ch. 205A. Controls on development of coastal areas do not restrict planting, cultivation, and harvesting of trees or other forest products, unless such activities have a cumulative negative impact on water resources. Under such conditions forest management is "development" and subject to permit requirement. In issuing permits, County Planning Commission must seek to minimize impact on water quality. Hawaii Rev. Stat. Ch. 181 prohibits discharge of poisonous or noxious effluent into streams or shorewaters. Specifies guidelines for reclamation. Hawaii Rev. Stat. Ch. 339 prohibits dumping of litter into water. Definition of "litter" does not include nonpoint pollutants.

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Oregon	Ore. Rev. Stat. Sec. 468.700 to 468.778. Enacted 1953; amended numerous times.	Department of Environmental Quality.	It is public policy to protect and improve water quality, and to prevent or abate pollution. Polluting water is not a reasonable or natural use of such waters and is prohibited, as is discharge of wastes which reduces quality. Environmental Quality Commission authorized to develop water quality standards based upon specifically enumerated quality criteria which are specified in statute. Persons who injure or destroy fish and wildlife or habitat are strictly liable for restoration costs.	Civil penalty of up to $500 per day of violation. Penalties for specified violations such as discharge permit violation up to $10,000 per day of violation.	Department of Environmental Quality has issued comprehensive water quality regulations. These include general guidelines and specific standards which apply to each individual drainage basin. Guidelines applicable to forestry address antidegradation, restrictions on log handling in public waters, and forest management activities. The latter are directed to be conducted in accordance with the Oregon Forest Practices Act (OFPA). Specific standards include water quality characteristics such as turbidity and temperature. Primary protection of water quality relative to forest management is thus derived from rules (BMP's) promulgated under the Forest Practices Act. These control impact of forest practices on water quality for three regions within state. Rules establish minimum standards for chemical use, slash disposal, reforestation, road construction, and harvesting. The rules have been certified by (Continued on next page)	Oregon Forest Practices Act (Ore. Rev. Stat. Sec. 527.610 to 527.730) authorizes promulgation of rules (BMP's) regarding forest management activities and protection of water quality. Rules are designed to assure sustained yields of timber while protecting water, air, and soil quality. State Board of Forestry authorized to adopt rules as minimum standards for forestry practices. Rules must maintain water, air and soil quality, and provide for protection of fisheries, wildlife habitat and sensitive ecological sites. Board must resolve any conflicts between rules and special management requirements of sensitive areas. Forest practice activities must conform to water quality standards. Rules recently changed to require a written management plan if harvesting is to occur within 100 feet of a class I stream or within 300 feet of a site inventoried for threatened and endangered species. Evaluation of OFPA indicates that forestry rules have been "moderately effective mechanism for improving water quality in forest streams". Violation of OFPA is a misdemeanor. Each day of violation is a separate offense. (Continued)

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Oregon (cont.)					the federal Environmental Protection Agency (EPA) as acceptable BMP's for purposes of the Federal Water Pollution Control Act.	Forest Practice Rules (Ore. Admin. Rules 629-24-101 to 646) include general rules and specific standards for each of 3 regions. General rules require notification of the State Forestry Division prior to conducting forest management activities and prior approval of stream channel alterations. General rules also provide for stream classification system, criteria for riparian area boundaries, limits on use of chemicals, and slash disposal guidelines. Regional rules cover all aspects of forest management. A provision for the protection of waters requires landowners to maintain riparian areas along the boundaries of Class I water. Ore. Rev. Stat. Sec. 390.805 to 390.925 establish Oregon Scenic Waterways System in which recreation, fish, and wildlife interests are of paramount importance. Department of Transportation authorized to adopt rules regarding management of lands adjacent to scenic waterways. Rules restrict road construction and require timber harvests be conducted to maintain aesthetic value of water. Department must be given notice prior to timber (Continued on next page)

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Oregon (cont.)						harvest for evaluation of impact on scenic water. Department may attempt to alter timber harvest plan or acquire land by purchase, gift, or scenic easement. Ore. Admin. Rules 736-40-005 to 095 require timber harvests to conform to preservation of scenic beauty of waterway. Department of Transportation management of "adjacent lands" includes all land within 1/4 mile of streambank, excluding lands which do not affect the view from scenic waterway. Management prescribed by Department is determined by subjective evaluation. Ore. Rev. Stat. Sec. 541.605 to 695 require permit for removal of any material from streambank, with exceptions for forestry activities in compliance with Forest Practice Rules. Ore. Rev. Stat. Sec. 549.400 prohibits obstruction or pollution of any waterway or drainage improvement.

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Washington	Washington Water Pollution Control Act. Wash. Rev. Code Ann. Sec. 90.48.010 to 90.48.910. Enacted 1971; amended 1973, 1975, 1983, 1985.	Department of Ecology.	It is state policy to insure water purity for all beneficial uses. Act creates Water Pollution Control Commission which is authorized to develop regulations and water quality standards. Any discharge which pollutes waters is prohibited. State may bring action against violators for costs of restoring environment. Department has sole responsibility for and authority over water quality standards and regulation of nonpoint sources of pollution in state. Regulations promulgated under state's Forest Practices Law must meet water quality standards and satisfy water pollution control laws. Department required to monitor water quality and has final authority to modify forest practice regulations as they pertain to water quality. Permit requirements and penalties imposed by Act do <u>not</u> apply to forestry activities that are in compliance with Forest Practices Act. Forest Practices Act and corresponding regulations must also satisfy requirements of Federal Water Pollution Control Act (33 USCA Sec. 1288, 1289, 1315).	Criminal: violations punishable by fine of up to $10,000 plus litigation costs. Violator may be imprisoned for up to a year. Each day of violation is separate offense. Civil: penalty of up to $10,000 per day of violation.	Department of Ecology has developed separate set of standards pertaining specifically to forestry operations. However, there is no criminal or civil penalty for degradation of water quality by practices which are in compliance with regulations issued under Forest Practices Act. Department of Ecology has not developed a forestry nonpoint pollution control program of its own. However, BMP's and regulations issued under Forest Practices Act are subject to modification by Department if they fail to meet water quality standards. Water quality characteristics relevant to forestry include those for temperature and turbidity. Forest Practices Act regulations have been certified as meeting requirements of Section 208 of Federal Water Pollution Control Act.	Forest Practices Act (Wash. Rev. Code Ann. Sec. 76.09.010 to 76.09.950) authorizes forest practices regulations which comply with Section 208 of Federal Clean Water Act concerning nonpoint pollution control. Department of Ecology may propose forest practices regulation relating to water quality in cooperation with Forest Practices Board; Department has final authority. Recent legislative changes authorize Department of Natural Resources to prepare hazard reduction plan for sites where soil erosion poses significant danger to public resources. Riparian zones protected by requiring some trees be left standing. Department of Natural Resources may issue "stop work" order, or a "notice to comply" to violators. Department of Ecology may enforce compliance with Act if Department of Natural Resources fails to do so. Violators may be subject to a fine of $500 per day of violation plus an additional penalty of $100 to $1,000 and up to one year imprisonment. (Continued on next page)

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Washington (cont.)						Statutory restrictions on authority of local governments to promulgate their own forest practice rules (Sec. 76.09.240(4)) held invalid in Weyerhauser v. King County (91 Wash 2d. 721, 1979). Forest Practices Rules and Regulations (Wash. Admin. Code Ch. 173-202-010 to 020). Regulations pertaining to water quality protection are individually adopted by Forest Practices Board and Department of Ecology after the agencies have reached agreement. Water quality provisions are found in forest practices regulations concerning timber harvesting, reforestation, road construction and chemical application. Evaluation of regulations in 1980 indicated that impact of forestry on water quality is relatively low overall, but impact from individual operations was severe in some cases. Recently proposed amendments are the product of broad consensus among government agencies, public interest groups, and forest products industry. Primary goal is to maintain viable forest industry and protect quality of natural resources. (Continued on next page)

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Washington (cont.)						Amendments accepted "in concept" by Forest Practices Board include (1) creation of riparian management zones, (2) limitations on road construction and timber harvests in riparian zones, and (3) further restrictions on application of silvicultural chemicals to protect water quality Wash. Rev. Code Ann. Sec. 7.48.010. Obstruction of stream channels used for rafting logs, timber, or lumber is a nuisance. Wash. Rev. Code Ann. Sec. 9.66.0-10. Unlawfully befouling, obstructing or interfering with a lake, navigable river, bay, stream, canal or basin is a public nuisance. Wash. Rev. Code Ann. Sec. 75.20.050 to 140 concern protection of streambeds from impacts by hydraulic projects. Department of Fisheries authorized to evaluate projects and deny approval or require modification to protect fisheries. Violation of Act is a gross misdemeanor and a public nuisance. Civil penalty of up to $100 per day of violation may be imposed. Recently proposed amendments suggest giving Department of Fisheries or Department of Game discretion on penalty imposed: either fine, or (Continued on next page)

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Washington (cont.)						gross misdemeanor charge punishable by fine and imprisonment. Wash. Rev. Code Ann. Sec. 76.32.040. This 19th century statute authorizes timber companies to channelize streams, remove obstacles, etc. Such improvement projects may not impede or obstruct stream outlets or interfere with use of such streams. Wash. Rev. Code Ann. Sec. 76.42.030 to 070 authorize Department of Natural Resources to remove wood debris from navigable waters. Disposal of wood debris into such waters is prohibited Wash. Rev. Code Ann. Sec. 79.01.128. Department of Natural Resources may modify management practices on public lands within municipal watersheds so that water quality exceeds state standards. Municipality must reimburse Department for additional management costs incurred. <u>Fransen v. State Board of Natural Resources</u> (66 Wash. 2d 672, 1965) held that state may not <u>sell</u> its forest lands to achieve statutory objective. Wash. Rev. Code Ann. Sec. 79.72.-010 to 900 authorize Department of Parks and Recreation to take measures to protect scenic rivers. To date Department has relied upon existing (Continued on next page)

Table C.4--Significant features of water quality legislation in the Pacific Coast region (continued)

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Washington (cont.)						regulations to protect scenic rivers' water quality. However, conservation plan with possible regulatory standards is under development. Wash. Rev. Code Ann. 88.28.050 imposes a fine of up to $200 per day upon persons who obstruct navigable streams, channels, or rivers, excluding booms to secure floating logs. Wash. Rev. Code Ann. Sec. 90.28.150 provides for stream improvements (clearing debris or straightening of channel) when necessary for logging. Shoreline Management Act of 1971 (Wash. Rev. Code Ann. Sec. 90.58.010 to 930) is designed to protect natural character, ecology, and public assess to shorelines, including banks of streams and lakes. Act requires permit for development along shorelines, including logging road construction. Harvesting within 200 feet of identified shorelines is limited to selective cuts of no more than 30 percent of merchantable volume. Other harvesting methods may be used if selective cut is ecologically detrimental, or for approved land development. Challenge to statutory limitation on road construction defeated (<u>Weyerhauser Co. v. King</u> 91 Wash. 2d 721, 1979).

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